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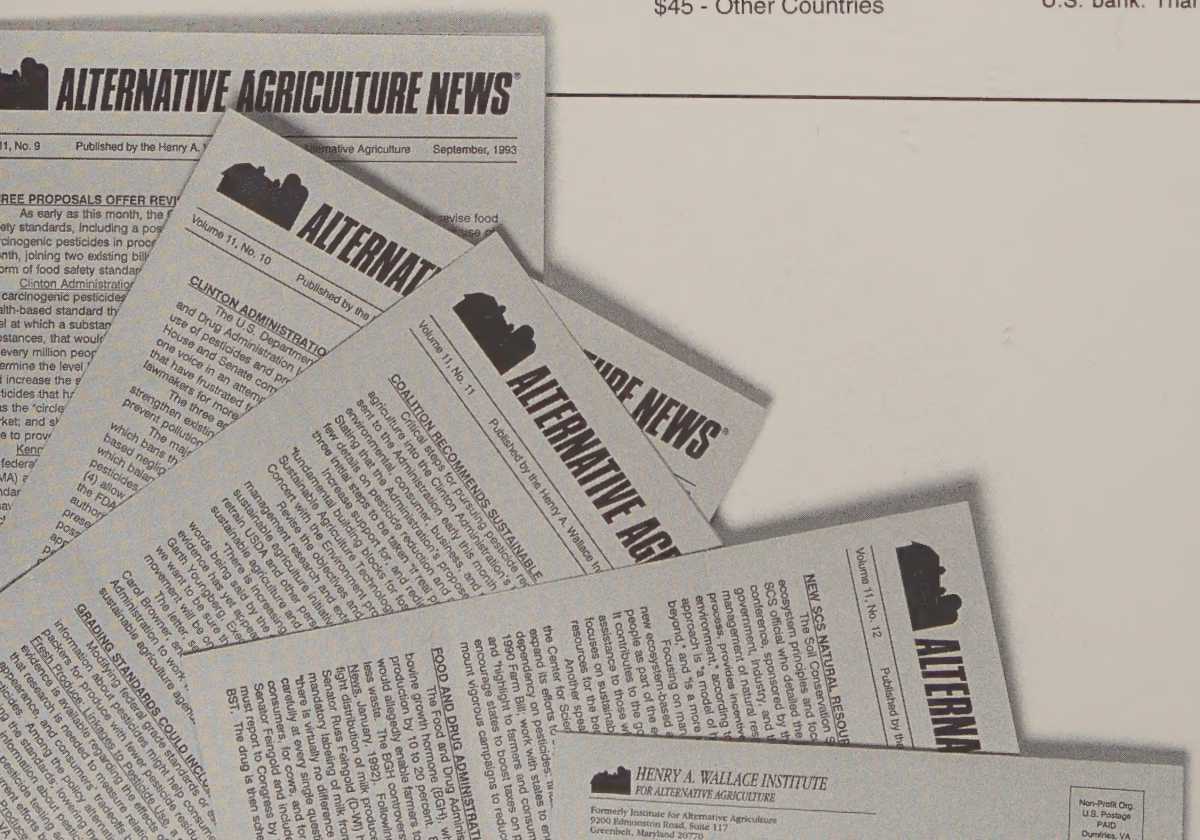

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Its programs include providing a national information clearinghouse, serving as a voice for sustainable agriculture in Washington, and developing and implementing research and educational outreach programs. It holds an annual scientific symposium and publishes a monthly newsletter.

The Institute is governed by a grass roots Board of Directors, which includes several commercial-scale organic farmers, and maintains a small professional staff. It is supported by memberships and donations and grants from foundations, corporations, and individuals.

Cover Photo

Potatoes, an intensively managed crop, are the focus of a cropping systems trial in Maine that examines the effects of soil and pest management, variety choice, and interaction of these factors on production.

Comparison of alternative pest and soil management strategies for Maine potato production systems

E.R. Gallandt, E.B. Mallory, A.R. Alford, F.A. Drummond, E. Groden, M. Liebman, M.C. Marra, J.C. McBurnie, and G.A. Porter

Abstract. *Potato acreage and total production in Maine have declined steadily since the 1960s. In 1991, a University of Maine research team established a large-scale, long-term, comparative study of three factors that form the foundation of productive potato cropping systems: soil management, pest management, and variety choice. This study, the Potato Ecosystem Project, included 96 main plots (5.8 ha total) and near-by "component studies." The project contrasted amended vs. unamended soil management strategies; conventional vs. reduced-input vs. bio-intensive pest management strategies; and disease and stress susceptible vs. tolerant potato varieties. Given recent concerns over resistance to pesticides and increasing costs of agricultural chemical inputs, the reduced-input and bio-intensive pest management systems provided encouraging results. Weed growth was similar in the conventional and reduced-input systems. Colorado potato beetle thresholds were exceeded less often and their densities were lower in the bio-intensive system than in the reduced-input and conventional systems. Lady beetles, which are major aphid predators, were more abundant in the bio-intensive pest management system compared with the reduced-input and conventional systems in 5 of the 6 years. Tuber yield and quality were maintained at a high level in the reduced-input system, although difficulties with plant disease, nutrient and weed management contributed to significantly lower yields in the bio-intensive pest management system. Economic analysis indicated that from 1993 to 1996, the reduced-input system had a greater return over variable cost (avg. \$973 ha^{-1}) than the conventional (avg. \$890 ha^{-1}) and bio-intensive pest management systems (avg. \$578 ha^{-1}). The amended soil management system achieved rapid improvements in soil quality: soil organic matter, water stable aggregates, potassium, and soluble inorganic phosphorus contents increased while requirements for synthetic fertilizers were reduced. These improvements in soil quality enhanced late-season crop vigor, canopy duration and tuber quality, and increased yields by 13% and 30% over the unamended system in 1994 and 1995, respectively, but not in 1996. Improved crop vigor in the amended soil management system also benefited weed control efforts by encouraging a more weed-suppressive potato crop. In the bio-intensive pest management system, in which weeds were controlled mechanically, the amended soil management system had less weed biomass than the unamended soil management system in 1994 and 1995. Conversely, the amended soil management system consistently increased flea beetle populations and, in one of two years, the incidence of Rhizoctonia. The choice of potato variety also affected pest dynamics. Total aphid density (all aphid species considered together) and almost all disease ratings were higher on 'Superior' than 'Atlantic' potato.*

Key words: cropping systems trial, soil management systems, pest management systems, reduced-input, bio-rational pest management, soil amendment, soil quality

Introduction

Potato (*Solanum tuberosum* L.) production has a long history in northern Maine. In recent years it has accounted for over 18 percent of the gross farm income in the state (NEASS, 1996). Despite its importance to the state's agricultural economy, the industry today has changed dramatically from its high point about thirty-five years ago. In 1970, Maine's 60,750 hectares of potato produced a crop totaling 1,618,995 Mg, but by 1990 acreage had dropped to 30,780 hectares and total production was 930,582 Mg (USDA, 1970 and 1990). Some, if not all, of this decline can be attributed to production economics. In four of ten years in the 1980s, growers

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were faced with negative net returns because of increased production costs, relatively constant yields and highly variable market prices (Westra and Boyle, 1991). Potato production relies heavily on purchased inputs with synthetic fertilizers, fuel, and pesticides accounting for approximately 30% of the total input cost of production (Westra and Boyle, 1991). Pesticide use is pervasive. In 1992, for example, 99% of Maine's potato acres were treated with herbicides, 96% were treated with insecticides, and 99% were treated with fungicides (USDA, 1993). If the declining trends in this industry are to be halted or reversed it is critical that management strategies be developed to increase net revenues by: reducing purchased inputs, increasing crop quality and therefore value, and/or increasing yields. There is a great need for management strategies that will address these options and thereby encourage a sustainable potato industry in northern Maine. Pest and soil management are central to farm productivity and offer possible strategies that alone or in specific combinations could increase net revenues while simultaneously satisfying goals related to environmental stewardship.

Traditionally, to address problems such as those faced by the Maine potato industry, researchers have developed, and growers have implemented, lower-cost alternatives for effective but expensive inputs. Additional inputs that decrease risk, improve yields, or decrease yield loss due to stress have also been introduced. In recent years, however, it has been recognized that simply substituting inputs may not be the best approach to solving agronomic and economic problems (MacRae et al., 1990). Recent long-term cropping system studies suggest that production systems may require extensive redesign to provide solutions congruent with agronomic, economic, and environmental goals (Brussaard, 1994; Kaffka, 1994; King and Buchanan, 1993; Peters et al., 1992; Posner et al., 1995; Smolik et al., 1995; Temple et al., 1994; Vereijken, 1986).

Alternative systems for potato production must satisfy high nutrient and pest management demands. Promising strategies are likely to include specific rotations, soil amendments, and integrated pest management tactics. In Atlantic Canada, for

Table 1. Insecticide and biocontrol agent applications for control of the Colorado potato beetle and aphid complex in three potato pest management systems. All applications except the predator releases were made when scouted densities exceeded action thresholds. Application rates, presented as ranges in the footnotes, varied between, and sometimes within, years.

	Pest Management					
	Conventional		Reduced Input		Bio-intensive	
Year	Number of applications[1]	Insecticide	Number of applications	Insecticide or biocontrol agent	Number of applications	Insecticide or biocontrol agent
Colorado potato beetle						
1991	1.00	esfenvalerate[2]	1.00	Bt[3]	none	
	1.00	endosulfan[4]	1.00	rotenone[5]		
1992	2.25	esfenvalerate	1.25	esfenvalerate	1.25	Bt + Bb[6]
					0.75	rotenone
1993	2.75	esfenvalerate	1.25	esfenvalerate	1.00	Bt + Bb[6]
					3.00	predator release[7]
1994	3.00	esfenvalerate	2.00	esfenvalerate	2.00	Bt + Bb[8]
					3.00	predator release
1995	3.00	azinphos-methyl[9]	3.00	azinphos-methyl	2.00	Bt + Bb[8]
	1.50	phosmet[10]	1.50	phosmet	3.00	predator release
	1.50	endosulfan	0.75	endosulfan	1.00	PBO[11]
					1.00	rotenone
1996	1.00	imadacloprid[12]	1.00	imadacloprid	1.00	Bt + Bb[8]
Aphid complex						
1991	1.00	methamidophos[13]	3.00	pyrethrum[14]	none	
1992	1.50	methamidophos	0.50	methamidophos	1.00	pyrethrum[15]
1993	0.25	methamidophos	0.25	methamidophos	5.25	pyrethrum[15]
1994	1.00	methamidophos	1.00	methamidophos	5.25	pyrethrum[15]
1995	1.00	methamidophos	1.00	methamidophos	none	
1996	none		none		1.00	pyrethrum[15]

[1] Number of applications presented for 1992 to 1996 represent the mean number over the four blocks for each pest management system. Action thresholds were as follows for the CONV system: 0.5 adults, 4.0 small larvae, or 1.5 large larvae per plant for CPB, and 1.0 winged GPA or 25% infested plants for total aphids. For the RI system in 1991, thresholds for both CPB and aphids were the same as in the CONV system, but for 1992 to 1996 RI thresholds were 1.0 adults, 8.0 small larvae, or 3.0 large larvae per plant for CPB, and 2.0 winged GPA or 50% infested plants for total aphids. For the BIO system in 1992, CPB thresholds were 1.0 adults, 4.0 small larvae, or 1.5 large larvae per plant, and for 1993 to 1996, 0.5 adults, 1.5 small larvae, or 1.5 large larvae per plant. Aphid action thresholds in the BIO system in all years were the same as the CONV system.

[2] Rate = 0.050-0.054 kg ai ha^{-1} + piperonyl butoxide (PBO), rate = 0.28 kg ai ha^{-1}.

[3] *Bacillus thuringiensis* (Foil®), Ecogen Corp., rate = 0.84 kg ai ha^{-1}.

[4] Rate = 0.42 kg ai ha^{-1}.

[5] Rate = 1.89 kg ai ha^{-1}.

[6] *Bacillus thuringiensis*, rate = 0.84 kg ai ha^{-1} mixed with *Beauveria bassiana* (Mycotech Bioproducts Inc.), rate = 5 x 10^{13} conidia/ha.

[7] Released 1.0 *Perillus bioculatus* predator nymph/plant.

[8] *Bacillus thuringiensis*, rate = 0.50 kg ai ha^{-1} mixed with *Beauveria bassiana* (Mycotech Bioproducts Inc.), rate = 5 x 10^{13} conidia/ha.

[9] Rate = 0.28 kg ai ha^{-1}.

[10] Rate = 1.02 - 1.18 kg ai ha^{-1}.

[11] Piperonyl butoxide, rate = 2.43 kg ai ha^{-1}.

[12] Rate = 0.05 kg ai ha^{-1}.

[13] Rate = 0.56 - 1.12 kg ai ha^{-1}.

[14] Rate = 0.065 - 0.074 kg ai ha^{-1}.

[15] Pyronone®, rate = 0.53 kg ai ha^{-1}.

Table 2. Fungicide applications in three potato pest management systems. Application rates, presented as ranges in the footnotes, varied between, and sometimes within, years.

	Pest Management					
	Conventional		Reduced Input		Bio-intensive	
Year	Number of applications	Fungicide	Number of applications	Fungicide	Number of applications	Fungicide
1991	9	mancozeb[1]	3	mancozeb	none	
	2	metalaxyl[2]				
1992	8	mancozeb	2	mancozeb	6	copper hydroxide[3]
	2	metalaxyl	.25	metalaxyl	.25	metalaxyl
1993	8	mancozeb	7	mancozeb	7	copper hydroxide
	2	metalaxyl	1	metalaxyl	1	metalaxyl
1994	15	mancozeb	13	mancozeb	13	copper hydroxide
	2	metalaxyl				
1995	1	chlorothalonil[4]	6	mancozeb	7	copper hydroxide
	8	mancozeb				
	2	metalaxyl				
1996	4	chlorothalonil	4	chlorothalonil	11	copper hydroxide
	7	mancozeb	7	mancozeb		
	2	metalaxyl				

[1] Rate = 0.67-1.68 kg ai ha^{-1}, except for two applications in each year 1994 to 1996 when rate = 0.17 kg ai ha^{-1}.
[2] Rate = 0.28-1.62 kg ai ha^{-1}.
[3] Rate = 0.27-1.41 kg ai ha^{-1}.
[4] Rate = 0.87-1.16 kg ai ha^{-1}.

example, a comprehensive review of available crop rotation data showed that a three-year potato/grain/forage rotation was profitable and performed well based on environmental criteria (ECSWCC, 1993). Other profitable rotations included potato/grain and potato/forage but maintenance of soil organic matter and diseases were problematic in these shorter rotations. A recent study in Finland demonstrated that an integrated system for managing potato had lower unit production costs and risk (variance of unit production costs) than either conventionally- or organically-managed systems (Varis et al., 1996). The integrated system may be viewed as an attempt to combine the "best of both worlds" through use of synthetic plus organic nutrient sources, economically efficient mechanical weed control, and decision-aide-based disease management.

"The Maine Potato Ecosystem Project," a comparative cropping systems study, included a factorial arrangement of pest and soil management systems designed to compare strategies that (i) increase efficiency of purchased inputs, (ii) substitute alternative tactics for conventional ones, and (iii) redesign multiple aspects of the production system. In regard to this last strategy, a soil management system that emphasized organic versus synthetic nutrient sources was examined. The goal of the former system was to rapidly build soil organic matter and improve soil physical properties. Although organic nutrient sources could be considered a "substitution" for synthetic sources, we view the changes in soil physical, chemical, and, particularly, biological processes to be a "redesign" of the ecosystem's function vis-a-vis van Bruggen (1995).

The overall goal of the Maine Potato Ecosystem Project was to examine management strategies that might lead to a more sustainable potato industry in northern Maine. The treatments selected, experimental design, and critical variables were agreed upon through a series of meetings involving the original University of Maine research team, Cooperative Extension personnel, and potato growers. In contrast to cropping systems trials that compare complete suites of conventional practices with optimized or alternative practices, the factorial design of this study allows explicit testing of possible main effects and interactions of soil management, pest management and crop variety. We chose this factorial design because we recognized that most growers seek to optimize their combination of these management factors without particular conviction to one of "our" cropping systems. Moreover, we recognized that growers are most interested in knowing whether pest and soil management strategies perform optimally in certain combinations or if they are robust enough to be used without regard to other system components. The Maine Potato Ecosystem Project's objectives were framed to answer the following applied and theoretical questions:

- Can the major insect, disease, and weed pests of potato be effectively and economically managed using reduced rates or alternatives to synthetic pesticides?
- How rapidly, and to what extent, can soil quality be improved through additions of green manure, animal manure, and compost?
- Does a fertility strategy that combines organic and synthetic nutrient sources effectively and economically benefit crop growth, yield, and quality?
- Does soil management directly or, through effects on crop growth, indirectly affect the dynamics of major insect, disease, and weed pests of potato?
- Should selection of pest and soil management systems consider stress tolerance of the potato variety to be planted?

To address these questions, we quantified (1) physical and chemical properties affecting soil quality; (2) pest population dynamics and pest-related crop yield loss; (3) crop yields and quality; and (4) economic performance. The background and results from the first four years of this study were published previously (Marra, 1996a). In this report we describe the key results from the six years that the project has been in place.

Materials and Methods

Site

The experiment (5.8 ha) was laid out on three fields at the Maine Agricultural

and Forest Experiment Station's Aroostook Research Farm located in Presque Isle, Maine. The soil for the entire site was a gravely, well-drained Caribou loam (fine-loamy, mixed, frigid, Typic Haplorthods) that contained extensive coarse fragments. Establishment of the experiment was described in detail previously (Porter, 1996).

General field procedures

Potatoes were grown in a two-year rotation, typical for northern Maine, and both rotation entry points (potato vs. rotation crop) were included in the experiment for an annual total of 2.9 ha of potato and 2.9 ha of rotation crops.

Treatments were arranged in a randomized complete block, split-plot design. Three pest management systems served as main-plot factors: conventional (CONV) vs. reduced input (RI) vs. bio-intensive (BIO). Subplot factors, in a fully factorial arrangement, included two soil management systems, "unamended" vs. "amended"; two potato varieties, Atlantic vs. Superior; and two rotation entry points, potato vs. rotation crop. Pest management system main plots were randomly assigned to locations within blocks; soil management system and variety treatment locations were randomly assigned within main plots. Rotation entry points were assigned to alternating positions within the field to create a patchwork of potato and rotation crop plots that would minimize, but not eliminate, movement of insect pests and beneficial natural enemies among the plots. There were four replicate blocks for a total of 96 plots (3 pest management systems x 2 soil management systems x 2 varieties x 2 rotation entry points x 4 replicates). Plot dimensions were 14.6 m x 41.0 m.

Plots were moldboard plowed in the fall of 1990 and in subsequent years were fall chisel plowed, tandem offset disked once or twice in the spring, and harrowed prior to planting. Seed tubers, either hand cut or small whole pieces, were planted in late-May to early-June in 91-cm rows. Within the row, seed pieces were spaced at an average of 24 cm and planted 5-10 cm deep using a "pick"-type planter. Blended fertilizer was applied in a band 5 cm below and 5 cm to the side of the seed pieces at planting. Potatoes were hilled once or twice; the first hilling was done at about 4 weeks after planting (near the time of tuber initiation) and the second hilling, if necessary, 1 to 2 weeks later. Vines were killed in the CONV system with two applications of desiccant (Diquat®, each at 0.28 kg ai ha^{-1}, plus X-77® surfactant, 0.125 % v/v) applied one week apart. In the RI plots vines were killed with one application of desiccant and one mechanical disturbance (rolling); and in the BIO plots with mechanical means alone (flail-type mower). In all systems, initial vine desiccation occurred between 8 and 12 September and approximately two weeks later tubers were harvested.

Table 3. Herbicides, cultivation and hilling used in three potato pest management systems.

Year	Conventional	Reduced Input	Bio-intensive
1991	metribuzin (1x)[1] hilling (2x)	metribuzin (1x) hilling (2x) cultivation (1x)	hilling (2x) cultivation (1x)
1992	metribuzin + paraquat (1x)[2] hilling (2x)	hilling (2x) cultivation (1x)	hilling (2x) cultivation (1x)
1993	metribuzin + paraquat (1x) hilling (2x)	metribuzin + paraquat (0.5x) hilling (2x) cultivation (1x)	hilling (2x) cultivation (1x)
1994	metribuzin + paraquat (1x) hilling (1x)	metribuzin + paraquat (0.5x) hilling (1x) cultivation (1x)	hilling (2x) cultivation (1x)
1995	metribuzin + paraquat (1x) hilling (2x) cultivation (1x)	metribuzin + paraquat (0.5x) hilling (2x) cultivation (1x)	hilling (2x) cultivation (1x) STH[3] (2x)
1996	metribuzin + paraquat (1x) hilling (1x) cultivation (1x)	metribuzin + paraquat (0.5x) (banded application) hilling (1x) cultivation (1x)	hilling (1x) cultivation (1x) STH (3x)

[1] Rate = 0.56 kg ai ha^{-1}.
[2] Metribuzin, rate = 0.56-0.84 kg ai ha^{-1}, mixed with paraquat, rate = 0.44-0.53 kg ai ha^{-1}.
[3] Spring-tine harrow (Lely®), one harrowing at 5% potato emergence and one post-emergence harrowing when potatoes were 8-10 cm tall.

Pest management systems

The Colorado potato beetle (CPB: *Leptinotarsa decemlineata* (Say)) and three species of aphids, the green peach aphid (GPA: *Myzus persicae* (Sulzer)), the potato aphid (*Macrosiphum euphoribiae* Thomas) and the buckthorn aphid (*Aphis nasturtii* Khaltenbach), are considered the primary insect pests of potato in northern Maine and were the focus of the insect control strategies. Insect control decisions in all pest management systems were based on weekly scouting of pest densities relative to action thresholds. In the CONV system, thresholds and insecticide recommendations were from the University of Maine Cooperative Extension Service (Dwyer et al., 1994) (Table 1). The RI system used the same insecticides as the CONV system but decisions to spray were based on higher thresholds and therefore had fewer applications of insecticides. The BIO system relied on a three-part strategy to control CPB: foliar applications of a bacterial pathogen (*Bacillus thuringiensis* Berliner) mixed with a fungal pathogen (*Bassiana bassiana* (Balsamo) Vuillemin) when action thresholds were exceeded, and releases of a predatory stinkbug (*Perillus bioculatus* Fabricius) during CPB oviposition. Aphids were controlled with pyrethrum in the BIO system when thresholds were exceeded. No insect control measures were used for rotation crops grown in sequence with potato.

Table 4. Crop sequence, fertilizer and amendment applications for the soil management system and rotation entry point treatment combinations during 1991 to 1996. All rates are per hectare.

	Soil management system			
	Unamended		Amended	
Year	Entry point 1	Entry point 2	Entry point 1	Entry point 2
1991	Potato 1120 kg 10-10-10[1] 60 kg N sidedress	Barley/Clover 45 kg N at planting 12 kg N topdress	Potato 504 kg 10-10-10 60 kg N sidedress 13 Mg compost 45 Mg manure	Barley/Clover 45 kg N at planting 12 kg N topdress 13 Mg compost
1992 Conventional and Reduced Input pest management systems				
	Barley/Clover 38 kg N at planting	Potato 1120 kg 10-10-10 59 kg N sidedress	Barley/Clover 38 kg N at planting 22 Mg compost	Potato 504 kg 10-10-10 59 kg N sidedress 22 Mg compost 45 Mg manure
1992 Bio-intensive pest management system				
	Pea/Oat/Vetch	Potato 66 kg N sidedress	Pea/Oat/Vetch 22 Mg compost	Potato 66 kg N sidedress 22 Mg compost 67 Mg manure
1993	Potato 1344 kg 10-10-10 50 kg N sidedress	Barley/Clover 38 kg N at planting 47 kg N topdress	Potato 627 kg 10-10-10 50 kg N sidedress 22 Mg compost 45 Mg manure	Pea/Oat/Vetch 22 Mg compost
1994	Barley/Clover 38 kg N at planting 45 kg N topdress	Potato 1344 kg 10-10-10 59 kg N sidedress 112 kg K_2O[2]	Pea/Oat/Vetch	Potato 672 kg 10-10-10 22 Mg compost 45 Mg manure
1995	Potato 1530 kg 10-10-10 56 kg N sidedress 112 kg K_2O	Barley/Clover 80 kg N at planting	Potato 750 kg 10-10-10 22 Mg compost 45 Mg manure	Pea/Oat/Vetch
1996	Barley/Clover 88 kg N at planting	Potato 1400 kg 10-10-10 57 kg N sidedress 116 kg K_2O	Pea/Oat/Vetch	Potato 653 kg 10-10-10 22 Mg compost 45 Mg manure

[1] Starter fertilizer analysis was 10% each N, P_2O_5, K_2O.
[2] Applied as KCl.

Extension guidelines were also followed for managing foliar diseases [early (*Alternaria solani*) and late blight (*Phytophthora infestans*)] in the CONV system and RI systems, with lower application rates and higher thresholds in the RI system (Table 2). The BIO system used a copper-based fungicide for prophylactic control of late blight, and in 1992 and 1993, metalaxyl for eradication of late blight in already infected potato plants. No fungicides were applied to rotation crops.

Weed management for potato in the three pest management systems differed in herbicide application and cultivation for weed control (Table 3); each system was treated uniformly with regard to hilling. Although not performed exclusively for weed control, hilling affects within- and between-row weeds. The barley (*Hordeum vulgare* L.)/red clover (*Trifolium pratense* L.) rotation crop was treated post-emergence with MCPA in the CONV and RI systems, 0.28 kg ai ha^{-1} and 0.14 kg ai ha^{-1}, respectively. Herbicides were not used in the BIO pest management system. In 1995 and 1996, a flex-tine cultivator was used post-emergence for weed control in the BIO barley. The green manure rotation crop was not treated with herbicides and was not cultivated in any of the pest management systems.

Soil management systems

The unamended and amended soil management systems differed in nutrient sources applied for potato, and crops grown in rotation with potato (Table 4). Potato grown in the unamended system received starter fertilizer (10% each of N, P_2O_5 and K_2O) at potato planting and nitrogen (as liquid urea ammonium nitrate, UAN) sidedressed at or near the time of tuber initiation. Based on soil test results, KCl was broadcast prior to potato planting in 1994 to 1996. In the alternating rotation crop year, the unamended system was planted during late May to early June with a barley grain crop (134 kg ha^{-1}) intercropped with rhizobium-inoculated red clover (11.2 kg ha^{-1}). In 1995 and 1996, the barley seeding rate in the BIO system was increased to 140 kg ha^{-1}, and 174 kg ha^{-1}, respectively, to compensate for mortality anticipated by post-emergence harrowing. Red clover was seeded after the harrowing in these years. In 1991 to 1994, the barley received nitrogen as ammonium nitrate at planting and was topdressed in 1991, 1993 and 1994 with additional nitrogen, as ammonium nitrate, after tillering. In 1995 and 1996, the barley received nitrogen at planting and no topdressing.

The amended soil management system was designed to make rapid improvements in soil quality. Prior to planting potato each year, the amended system received beef manure and cull potato compost (Table 4). Amendments were spread and incorporated by disking in the spring prior to potato planting; in 1994 manure application was switched to the fall. The potato crop also received starter fertilizer (10% each of N, P_2O_5, K_2O) at planting. Depending on the results of petiole N analysis, variable rates of nitrogen (as UAN) were sidedressed at or near the time of tuber initiation; no sidedressing was necessary from 1994 to 1996. In the alternating rotation crop year, the amended system

was planted with a green manure mixture of oat (*Avena sativa* L.), pea (*Pisum sativum* L.) and hairy vetch (*Vicia villosa* L. Roth) (54, 168, and 34 kg ha^{-1}, respectively, seeded during early- to mid-June) that was grown without supplemental fertilizer. At the start of the experiment the amended soil management system included barley/red clover as a rotation crop in the CONV and RI systems but over 1992 and 1993 the green manure replaced barley/red clover in these systems (Table 4). From 1991 to 1993, cull potato compost was applied to the amended-system rotation crops, as well as to the potato crop.

Monitoring soil physical and chemical characteristics

Percent organic matter and water-stable aggregate content were determined from soil samples taken each spring prior to the application of organic amendments. Ten soil cores were collected to a 15-cm depth from each plot, air dried, sieved through a 6.4-mm screen, bulked, and mixed thoroughly. Duplicate subsamples from each bulked sample were analyzed for readily oxidizable organic matter using the Walkley-Black method (Nelson and Sommers, 1982). Water-stable soil aggregate content was also determined from these samples according to the method described by Porter and McBurnie (1996). Soil was sampled again in the fall to determine mineral nutrient content. Ten soil cores were collected to a 23-cm depth from each plot, bulked, mixed, and a single sample was removed to represent an entire plot. These samples were dried, sieved, and submitted to the University of Maine Soil Testing Laboratory for analysis using standard methods (Hoskins, 1997; NCCST, 1995). A modified Morgan procedure was used for phosphorus and cation extraction (NCCST, 1995).

Potato crop

Petiole samples were collected at one or more dates during each growing season. Thirty recently expanded leaves (generally the fourth or fifth leaves from the top of the plants) were collected. Leaflets were stripped from the petioles and discarded. Petioles were then dried at 60°C, ground, and analyzed for nitrate-nitrogen content using the method described by Porter and Sisson (1991).

Yields of the potato crop were determined from the four center rows of each plot (25% of each plot area). Tubers were lifted with a two-row potato digger, collected by hand, and the yield of the entire four rows was weighed in the field. Where tuber rot was prevalent, any decaying tubers were weighed separately in the field. Two 22.7-kg subsamples were taken from the yield rows of each plot for quality evaluations. These samples were graded for rot and external defects (i.e., sunburn, growth cracks, off shapes, scab) and then sized on a spool-type sizer. U.S. #1 yields were calculated as yield of tubers between 4.8 cm and 10.2 cm diameter, excluding diseased and defective tubers. Once the yield rows were removed, the remaining 12 rows of each plot were harvested with a conventional, two-row potato harvester.

Barley and green manure crop sampling

Six quadrat samples (0.5 m^2 each) were collected from each barley plot to determine grain and straw production before harvesting with a combine. Additionally, two 1.5-m wide swaths (0.006 hectares each) were harvested from each plot with a small-plot combine to determine grain yield.

In green manure plots six quadrat samples (0.5 m^2 each) were clipped at soil level and collected during October of each year to determine final aboveground biomass yields by the species present. Three of the quadrat samples were pooled to create a single aggregate yield sample. The remaining three quadrat samples were sorted to determine biomass of the individual crops and total weeds. A representative subsample of the aggregate green manure mixture was dried, ground, and submitted to the University of Maine Analytical Laboratory for nitrogen analysis.

Sampling Insect Pests and Natural Enemies

Insects in each potato plot were sampled once per week throughout the growing season. In 1991 and 1992, 50 random plants per plot were examined initially. As plants increased in size, sampling was reduced to 30 plants per plot. In 1993 through 1996, 30 plants per plot were sampled initially, and the number was reduced to 20 plants per plot during August. The densities of CPB adults and large larvae (third and fourth instars), potato flea beetle (*Epitrix cucumeris* (Harris)) adults and damage, green peach aphid, potato aphid, buckthorn aphid and lady beetles were recorded per plant. CPB and aphid densities were summarized weekly to determine if economic thresholds for these pests were exceeded and if insecticide treatments were necessary. Seasonal densities or season incidence of insects were estimated for each plot by integration of the insect-count time series (Groden, 1989).

Disease Monitoring

The two most serious foliar pathogens of potato in northern Maine are early blight and late blight. All potato plots were monitored for these and other diseases as described for sampling insect pests and natural enemies (above). Suspected infected foliage was recorded and collected. The collected foliage was brought to the plant pathology laboratory facility at the research farm and causal agents were identified. Potatoes were destructively sampled at mid-season and evaluated for symptoms of the soil-borne pathogen *Rhizoctonia solani*. Potato "early-dying," premature senescence usually associated with the soil-borne fungi *Verticillium dahliae* and *Colletotrichum* sp., was examined by direct plating of sap squeezed from surface-sterilized potato stems. Details regarding the methods used for monitoring of plant diseases have been published previously (Lambert and Salas, 1996).

Measuring weed dynamics

Weed dynamics were followed only in Atlantic potato. Weeds in potato were measured by quadrat sampling in early- to mid-August. Plant material in eight 0.25-m^2 quadrats was cut at the soil surface, sorted to species, bagged, dried for > 5 days at 70°C, and weighed.

Measure of economic performance

Return over variable cost was used as the measure of economic performance. It

Table 5. Monthly rainfall amounts at Aroostook Farm, Presque Isle, Maine, 1991 to 1996.

Month	Monthly Rainfall by Growing Season						30-year Average
	1991	1992	1993	1994	1995	1996	
	(mm)						
May	82	38	83	115	58	101	75
June	22	107	141	118	39	93	86
July	20	93	51	81	61	130	105
August	217	128	76	32	61	65	96
September	97	52	131	92	56	101	90
Totals							
June-Aug.	259	330	267	231	161	288	287
May-Sept.	437	419	483	437	276	491	452

Table 6. Select soil physical and chemical properties of the unamended (-) and amended (+) soil management systems.

Year	Organic matter			Total water stable aggregrates			Soil phosphorus			Soil potassium		
	−	+		−	+		−	+		−	+	
	(% dry weight basis)			(% dry weight basis)			($kg\ ha^{-1}$)			($kg\ ha^{-1}$)		
1991	2.66	2.70	ns	25.7	25.6	ns	28.1	27.8	ns	358	377	ns
1992	2.69	3.05	**	25.1	25.8	ns	29.7	29.7	ns	272	321	**
1993	2.82	3.20	**	31.2	34.3	**	28.6	29.3	ns	241	302	*
1994	3.02	3.77	**	24.6	31.0	**	33.2	37.5	**	252	392	**
1995	3.31	4.68	**	25.7	34.4	**	42.3	51.9	**	382	552	**
1996	3.04	4.08	**	23.8	32.1	**	34.9	41.3	**	298	404	**

was calculated by subtracting the sum of all variable production costs (seed, fertilizer, amendments, pesticides and field operations) from the total gross returns (revenue from potato and, in the case of the unamended system, from barley). While this measure does not include ownership costs (i.e., fixed costs such as land, building and machinery ownership costs, taxes and rent) and, therefore, can not predict overall profitability of the treatments, return over variable costs does reflect relative profitability. Return over variable costs were calculated for the full two-year rotation and are expressed in $\$\ ha^{-1}$, assuming that one-half hectare is in potato and one-half hectare is in a rotation crop.

Input prices were adjusted to reflect 1995 dollars, and the index of prices paid by farmers (USDA, 1995, 1995 - 1997) was used to estimate the prices for the other years. To reflect commercial-scale production, 1995 material prices were determined by surveying three agricultural products dealers in Aroostook County and taking the average of their quotes. Exceptions were prices for the amendments, two of the biological insect control materials, and the potato seed. Potato cull compost, for which there was only one source in Aroostook County, and manure were valued at the prices paid by the experimental farm in 1995. Only hauling costs were paid for the manure; the manure itself was free. A 1995 *Beauveria* cost estimate of \$10 per $1x10^3$ conidia was obtained from Mycotech Bioproducts, Inc. (Pauline Woods, January 1996, personal communication), but it does not necessarily reflect what the cost will be once this biological control is commercially available. While price estimates for *Perillus bioculatus* were also obtained based on current laboratory-scale production techniques, estimates of the cost of using this natural enemy were not considered reliable on a commercial scale and were not included in the profitability calculations (Marra, 1996b). Potato seed prices were determined by taking a 5-year average (1991-1995) of what the experimental farm paid for seed ($\$198\ Mg^{-1}$).

The 1995 base potato selling price was the 10-year average for Maine fall potatoes, $\$137\ Mg^{-1}$ (1986-1995) (USDA, 1988-1996) and the 1995 base barley selling price was quoted from an extension educator in Aroostook County, \$0.08 kg^{-1} (M. Williams, 1995, personal communication). Selling prices for other years of the project were estimated by assuming a 2% yearly increase to keep pace with the average increase in prices paid for inputs.

Machinery operation costs were calculated according to methods described in the ASAE standards (1995), and were adjusted yearly according to the USDA Index of Prices Paid by Farmers (1995 and 1995-1997) for fuel and labor. Labor to operate the machines was valued at \$8.00 $hour^{-1}$ in 1995. It was assumed that barley was custom combined at a 1995 price provided by an Aroostook County extension educator (M. Williams, 1995, personal communication) and adjusted yearly according to the USDA farm services index.

Statistical analysis

Randomized complete-block, split-plot design analysis of variance was used to determine the significance of treatment effects on the many variables measured. Treatment means were separated using Fisher's least significant difference test.

Results and Discussion

Weather conditions

Precipitation data show that 1991 had unusually dry months of June and July,

and a wet August; 1992 had relatively high June to August rainfall; 1993 and 1994 were unusually dry during July and August, respectively; 1995 was a year of severe drought; and 1996 was slightly wetter than normal through July (Table 5).

Rotation crops and amendments

Barley grain yield in the unamended soil management system averaged 3.3 Mg ha^{-1}. Pest management system differences were significant in only two years. In 1995, the BIO system had greater weed biomass and consequently yielded 1.0 Mg ha^{-1} less than the RI and CONV systems. In 1996, the barley seeding rate was increased to compensate for anticipated injury due to flex-tine harrowing. This resulted in greater head densities and a 0.6 Mg ha^{-1} yield gain over the RI and CONV systems.

Barley/red clover returned an annual average of 4.0 Mg dry matter ha^{-1} to the soil compared with 6.8 Mg dry matter ha^{-1} for the green manure rotation crop. In addition to the green manure crop, the potato crop of the amended system received annual additions of compost (average 6.6 Mg dry matter ha^{-1}) and manure (average 16.5 Mg dry matter ha^{-1}) for a total dry matter loading of 29.9 Mg ha^{-1} per year. Compost was also applied to the rotation crop from 1991 to 1993, adding another 6.0 Mg dry matter ha^{-1} (annual average) in those years. The compost, manure and green manure contributed an annual average of 528 kg ha^{-1} of total nitrogen, 180 kg ha^{-1} of potassium and 126 kg ha^{-1} of phosphorus to the amended system.

Soil physical and chemical properties

The amended soil management strategy caused rapid changes in soil quality through the additions of large amounts of organic amendments. Organic matter was significantly greater in the amended soils after only one season and the water stable aggregate content was significantly greater within two seasons (Table 6). The latter result indicates that soil structure was enhanced and suggests that the soil would be more resistant to dispersion and erosion. The amended soil management system reduced requirements for synthetic fertilizer by 52% (Table 4) yet maintained potato yields equal to or greater than the unamended system in all years except 1996 (Table 8). Soil test potassium and phosphorus levels were also higher in the amended system (Table 6). In fact, overloading of phosphorus should be a concern since soils with elevated phosphorus can be detrimental to surface water quality if eroded. Soil test phosphorus levels in the amended system since 1994 were over 30 kg ha^{-1}, high enough that response to phosphorus fertilizer would be unlikely (Fitzgerald, 1997).

Table 7. Pest management system, soil management system, and potato variety effects on incidence of disease in potato. The most problematic pathogens at this location included early blight (*Alternaria solani*), late blight (*Phytopthora infestans*), black scurf (*Rhizoctonia solani*) and a group of fungal pathogens including *Verticillium* spp. and *Colletotrichum* spp. that are associated with potato "early-dying." From Lambert and Salas (1996).

Year	Pest mgt. System[1]			Soil mgt. system		Potato variety	
Pathogen	CONV	RI	BIO	Unamended	Amended	Atlantic	Superior
1993	Diseased tissue (%)						
P. infestans	1 a[2]	0 a	3 b	1 a	1 a	2 b	1 a
A. solani	5 a	6 a	6 a	6 a	5 a	2 a	9 b
R. solani	-	-	-	15 b	12 a	11 a	17 b
	Colony counts (no. per 0.1 ml stem sap)						
Verticillium spp.	-	-	-	-	-	-	-
Colletotrichum spp.	-	-	-	-	-	-	-
1994	Diseased tissue (%)						
P. infestans	-	-	-	-	-	-	-
A. solani	-	-	-	-	-	-	-
R. solani	16 ab	20 b	14 a	17 a	16 a	13 a	20 b
	Colony counts (no. per 0.1 ml stem sap)						
Verticillium spp.	127	125	1005 **	557	281 ns	63	572**
Colletotrichum spp.	5	4	187 **	83	48 ns	18	116 **

[1] CONV = conventional; RI = reduced input; and BIO = bio-intensive.
[2] For each pathogen species, within a given year, data followed by common letters are not significantly different (p = 0.05). Not reported (-).

Insects

Economic thresholds for the CPB were exceeded less often in the BIO pest management system than in the CONV system in all years of the study except 1996, when thresholds in both systems were exceeded only once. CPB thresholds were generally exceeded less often in the RI system than the CONV (thresholds were higher in RI system, see methods), but in most years (4 out of 5) thresholds were exceeded in the RI and BIO systems. As a result, foliar insecticides for CPB control were applied more frequently in the CONV system than the RI, and more frequently in the RI than the BIO (Table 1). Even with fewer applications of foliar insecticides, CPB large larval densities were lowest in the BIO system from 1993 to 1996 (Fig. 1A). Fewer summer adult CPB were observed in the BIO system compared with the CONV and RI systems, and as a result, the relative density of colonizing adults the following spring was lower in the BIO system (Fig. 1B). This indicates a possible between-year or long-term effect of the BIO management strategy on CPB densities that has not been observed in the other systems. We hypothesize that persistence of *Beauveria bassiana* in the CPB population and/or soil is responsible for the long-term CPB suppression.

Aphid populations were difficult to manage in the BIO system in 1993 and 1994. Economic thresholds for aphids were exceeded more than 5-fold in this

Table 8. Pest management system, soil management system and potato variety effects on yields of U.S. #1 potatoes (Mg ha^{-1}).

	1991	1992	1993	1994	1995	1996
	Mg ha^{-1}					
Maine state average[1]	25.8	33.6	28.6	27.4	24.6	30.8
Main effect averages						
Pest management system						
Conventional	26.0a	35.6a	29.5	30.5a	21.5a	34.2a
Reduced Input	18.9b[2]	36.3a	28.7	30.4a	20.9a	34.2a
Bio-intensive	15.8b[2]	20.9b[3]	28.2	22.0b	17.1b	29.0b
Soil management system						
Unamended	19.4	30.1	27.7	26.0b	17.2b	34.0a
Amended	21.1	31.8	29.9	29.2a	22.5a	30.9b
Potato variety						
Atlantic	21.6a	30.5	30.4a	29.2a	22.4a	32.6
Superior	18.8b	31.5	27.2b	25.9b	17.4b	32.4
ANOVA results	p-values					
Pest management system	<0.01	<0.01	ns	<0.01	<0.01	<0.01
Soil management system	ns	ns[4]	ns	<0.01	<0.01	<0.05
Variety	<0.01	ns	<0.05	<0.01	<0.01	ns
Interactions	ns	ns	ns	ns	ns	ns

[1] From New England Agricultural Statistics Service, 1996. 1996 yield is a preliminary estimate.
[2] Reduced Input pest control methods were primarily biological during 1991 except for disease control and vine desiccation. No pest control methods were used in the Bio-intensive system in 1991.
[3] Bio-intensive plots did not receive any at-planting fertilizer in 1992.
[4] Tested within pest management system.

system compared with 0.25 and 1.0 times in the CONV and RI systems during these years, respectively (Table 1). However, densities of aphids declined in all systems in subsequent years, and were significantly lower in the BIO system in 1995 compared with the other systems (Fig. 2A) even though foliar applications of pyrethrum were not applied during that year (Table 1). Lady beetles were the most abundant predators observed in the potatoes throughout the study (Drummond and Groden, 1996). In all years except 1996, they were more abundant in the BIO system than the other pest management systems (Fig. 2B). It is likely that the BIO management system conserves more lady beetles, but comparison of lady beetle densities with aphid densities through the six years of this study would suggest that lady beetles do not consistently suppress aphid populations below economic thresholds. However, the dramatic decline of aphid populations in 1995 and 1996 did coincide with explosive populations of the newly introduced multi-colored Asian lady beetle (*Harmonia* sp.) in the region.

Potato variety and soil management systems did not have consistent effects on CPB densities. Only aphids responded differentially to potato variety (Fig. 3A) and only adult potato flea beetles responded differentially to soil management systems (Fig. 3B). Superior potatoes supported significantly higher aphid densities than Atlantic in 1992 to 1994, with a similar trend (not significant) during 1995 and 1996. The reason for the consistently higher aphid abundance on Superior potatoes is unclear, but may be due to varietal differences in the foliage nitrogen content (see p. 99, Drummond and Groden, 1996 and p. 30-36, Porter and McBurnie, 1996). Adult fleabeetle densities were consistently higher in the amended plots than in the unamended plots. It is not known whether this effect is due to differential flea beetle survival or colonization preference. Pest management systems and variety did not result in differences in potato flea beetle populations.

Diseases

Late blight was not problematic during the first two seasons of the experiment (data not shown). However, metalaxyl-resistant strains of *P. infestans* became epidemic in northern Maine, and at the study site, in 1993 when incidence ranged from 1 to 28% (Lambert and Salas, 1996). During this year, late blight was more abundant in the BIO than in the RI and CONV pest management systems (Table 7), suggesting lower efficacy of the copper-based fungicide relative to mancozeb (Table 2). Foliar late blight ratings indicated that the disease was less severe in Superior compared to Atlantic potato, although overall incidence was very low (Table 7); late blight infecting tubers was more prevalent and followed this same trend (9% vs. 6% infection in the Atlantic and Superior varieties, respectively). Early blight, in contrast, was unaffected by the pest management systems, and was more severe in Superior compared with Atlantic potato (Table 7). *Rhizoctonia* black scurf was likewise more severe in Superior compared with Atlantic potato. Perhaps because of the prevalence of these primary pathogens, early-dying was not observed in 1993.

Neither late blight nor early blight was problematic during 1994 but the season was not without disease problems. Early-dying was observed in the BIO, Superior plots beginning in mid-August. Significant main effects of pest management system and potato variety demonstrated high levels of *Verticillium spp.* and *Colletotrichum spp.* present in the sap of BIO potatoes, and in the sap of the Superior variety (Table 7). Soil management system did

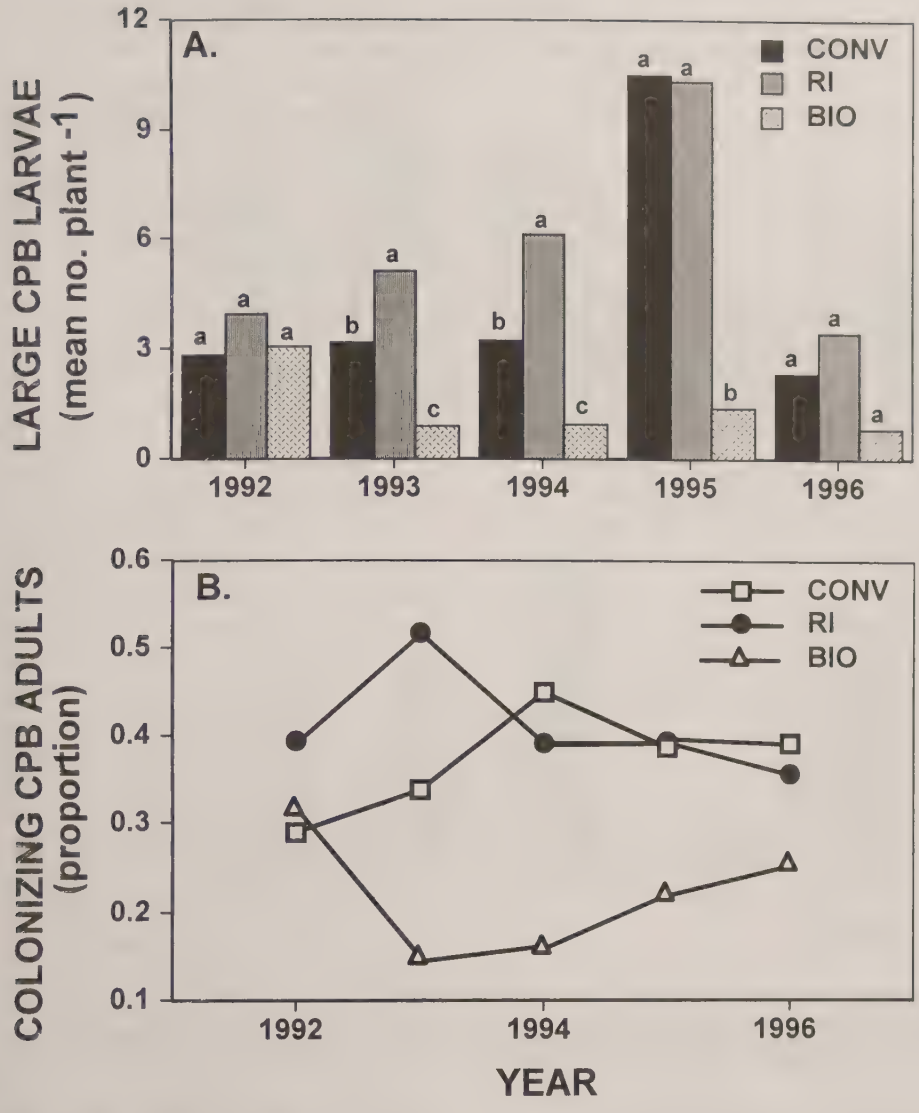

Fig. 1. The seasonal densities of Colorado potato beetle (CPB) large larvae (A) and the proportion of total colonizing (prespray) CPB adults (B) for conventional (CONV), reduced input (RI) and bio-intensive (BIO) pest management systems in 1992 to 1996. Columns with the same letter indicate no significant differences between treatments in that year.

not affect the abundance of these pathogens. In 1995, a year of severe drought (Table 5), there were few disease problems observed in any treatments. Disease severity data for 1995 and 1996 were not available.

Crop residues and organic amendments can cause a myriad of soil physical and chemical changes that could either encourage or inhibit soil-borne pathogens. Managing soils with more diversified rotations and organic amendments could thus increase disease severity, a concern commonly expressed by Maine potato growers. There is also the possibility that these management strategies could encourage the development of disease-suppressive soils (Huber and Watson, 1970; van Bruggen, 1995). Ideally, a disease-suppressive soil would reduce survival, germination, and growth of *P. infestans* thereby reducing the local inoculum sources that can lead to epidemics. Blackford (1997) examined the effect of the unamended and amended soil management systems on *P. infestans*. Sporangia survival was unaffected by soil management and, although short incubation periods indicated that sporangia germination was equal in the two soil management systems, an experiment that included a longer incubation period demonstrated that germination was reduced by 9% in the amended relative to the unamended system (Blackford, 1997, p. 51). Soil management did not affect mycelial growth rates in these studies.

Weeds

From 1991 to 1993, and in 1996, total above-ground weed biomass in potato was affected only by the pest management systems; soil management effects were not detected (Fig. 4A). Biomass was consistently low, < 20 kg ha^{-1}, in the CONV system demonstrating the effectiveness of metribuzin and paraquat, at full labeled rates, without supplemental cultivation. Through 1995, the BIO system consistently had the greatest amount of weed biomass, 10 to 60-fold greater than the CONV system. This indicated that substituting two cultivations for recommended herbicide applications resulted in comparably less control and greater total weed biomass. In 1996, the BIO system received timely and intensive cultivation with the flex-tine harrow (3 times), cultivation with sweeps, and hilling (Table 3). This combination of mechanical disturbances provided weed control equivalent to the CONV system.

Herbicides were not applied to the 1991 and 1992 RI systems and the total weed biomass in these years was similar to the BIO system. From 1993 to 1995, the RI system utilized low rates of metribuzin and paraquat. As a result, weed biomass was low and similar to the amount measured in the CONV system. In 1996, an attempt was made to further reduce the pesticide input in the RI system by banding herbicides. Weed biomass was greater in the RI system than in the CONV and BIO systems (Fig. 4A). Poor performance of the banded herbicide application was likely related to equipment problems that made it difficult to maintain the herbicide band centered on the potato row.

In 1994 and 1995, total weed biomass in potato was affected by an interaction of pest management and soil management systems (Fig. 4B and 4C). In the BIO system, which relied on cultivation without supplemental herbicide application, total weed biomass in 1994 was 77% less in the amended than in the unamended system. Similarly in 1995, total weed biomass in the BIO system was 68% less in the

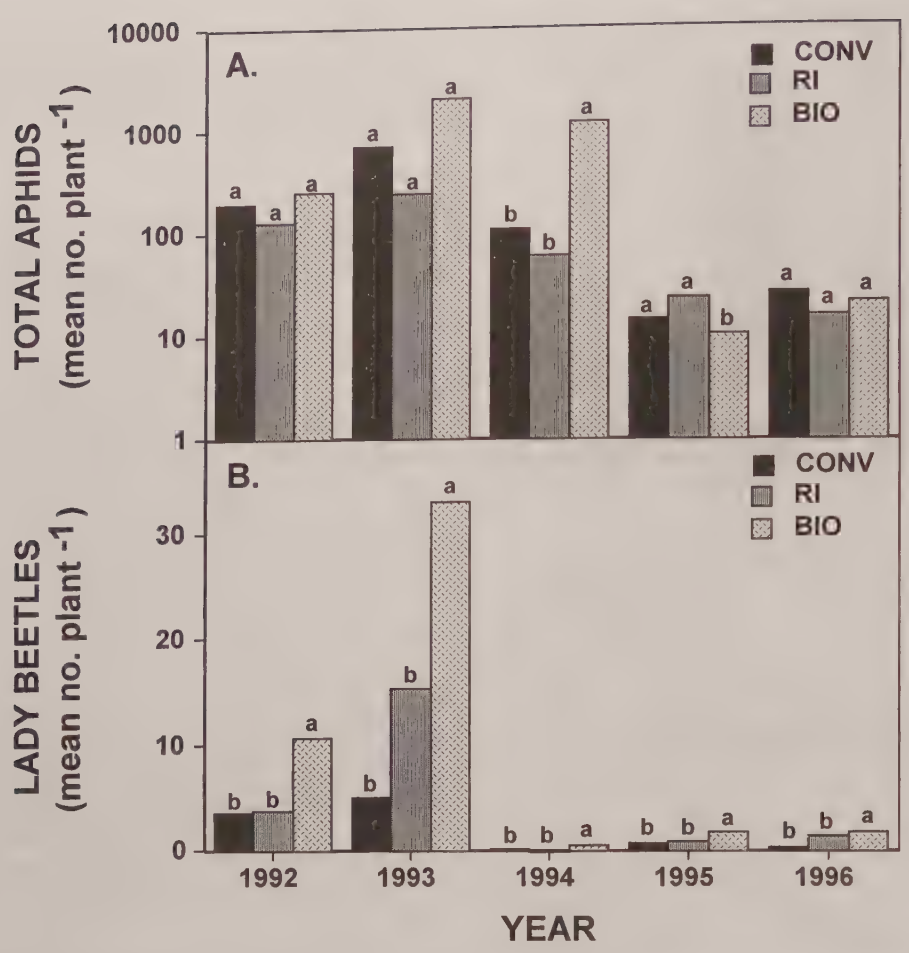

Fig. 2. Influence of conventional (CONV), reduced input (RI) and bio-intensive (BIO) pest management systems on aphid (A) and lady beetle (B) density in 1992 to 1996. Columns with the same letter indicate no significant differences between treatments in that year.

amended than in the unamended soil management system. The greater amount of weed biomass in 1995 relative to 1994 (Fig. 4B and 4C) probably reflected the combined effects of (i) better performance of weeds relative to the crop under severe drought conditions (Table 5) and (ii) the 10-day later sampling date. The CONV and RI systems, which included full and one-half rates of herbicides for direct weed control, contained an equal and low (< 10 g m^{-2}) amount of weed biomass in the amended and unamended systems (CONV vs. RI x SM, $p > 0.05$ in both 1994 and 1995). The pest management by soil management interaction was mostly due to effects on common lambsquarters (*Chenopodium album* L.), the dominant species (by weight) in the experiment. Barnyardgrass (*Echinochloa crusgalli* [L.] Beauv.) + Japanese millet (*Echinochloa frumentacea* [Roxb.] Link), low cudweed (*Gnaphalium uliginosum* L.), and common hempnettle (*Galeopsis tetrahit* L.) biomass responded only to main effects of either pest management system or soil management system (data not shown). In 1994, weed effects on yield were not detected, however, in the 1995 BIO system, weeds reduced yield 37% in the unamended soil management system whereas there was no significant yield loss in the amended system (data not shown; Gallandt et al., 1998). Potato leaf area (data not shown) and tuber yield (Table 8) suggest that, relative to the unamended soil management system, the amended system promoted a more vigorous and weed-suppressive potato crop.

Potato crop production

Yields of potato from the CONV system were within 15% of the average Maine potato yields in each year and exceeded the state average in all years but 1995 (Table 8). The yearly variation in yields closely followed seasonal rainfall patterns (Table 5). Yields were highest during the 1992 and 1996 seasons when rainfall was plentiful and well-distributed, low in 1994, which had a dry August, and lowest during the dry 1995 season.

Yields of potato in the RI system were similar to those of the CONV system in every year but the first (1991) when RI pest control methods were primarily biological (Table 8). In all other years, potato yields were equal in these two systems despite the fact that the RI system received on average 26% fewer kilograms of pesticide active ingredient per hectare. It should be noted, however, that we did not evaluate these systems under severe late blight pressure. Also, we were not able to assess differences in the long-term, large-scale storage ability of the potatoes. Both of these factors could strongly affect marketable yields and net returns.

Yields for the BIO system were equal to that of the CONV system in 1993 but in all other years it was less. Lower yields in the BIO system were the result of a variety of factors, some of which reflected experimentation with this system. In the initial year of the experiment, the BIO plots were treated as "control" plots and did not receive any pest control. In 1992, at-planting fertilizer was not applied to the BIO system in an attempt to rely solely on amendments for both early- and later-season nutrients. Tissue analysis revealed that potatoes in this system were nitrogen stressed (data not shown), resulting in lower yields. In 1994, early-dying was observed in the BIO system, which may have been related to the higher levels of *Verticillium* and *Colletotrichum* (Table 7). Greater use of the copper fungicide (Table 2) may have led to crop stress and enhanced levels of these disease organisms. In 1995, weed pressure was high in the BIO system and accounted for a large portion of the yield depression (Fig. 4C). Finally, in 1996, disease was suspected as the cause of the lower yields in the BIO system. In this year, weed pressure was relatively low (Fig. 4A), as were CPB and aphid populations (Figs. 1A and 2A). Use of the copper fungicide was high (Table 2) and, again, may have stressed the crop

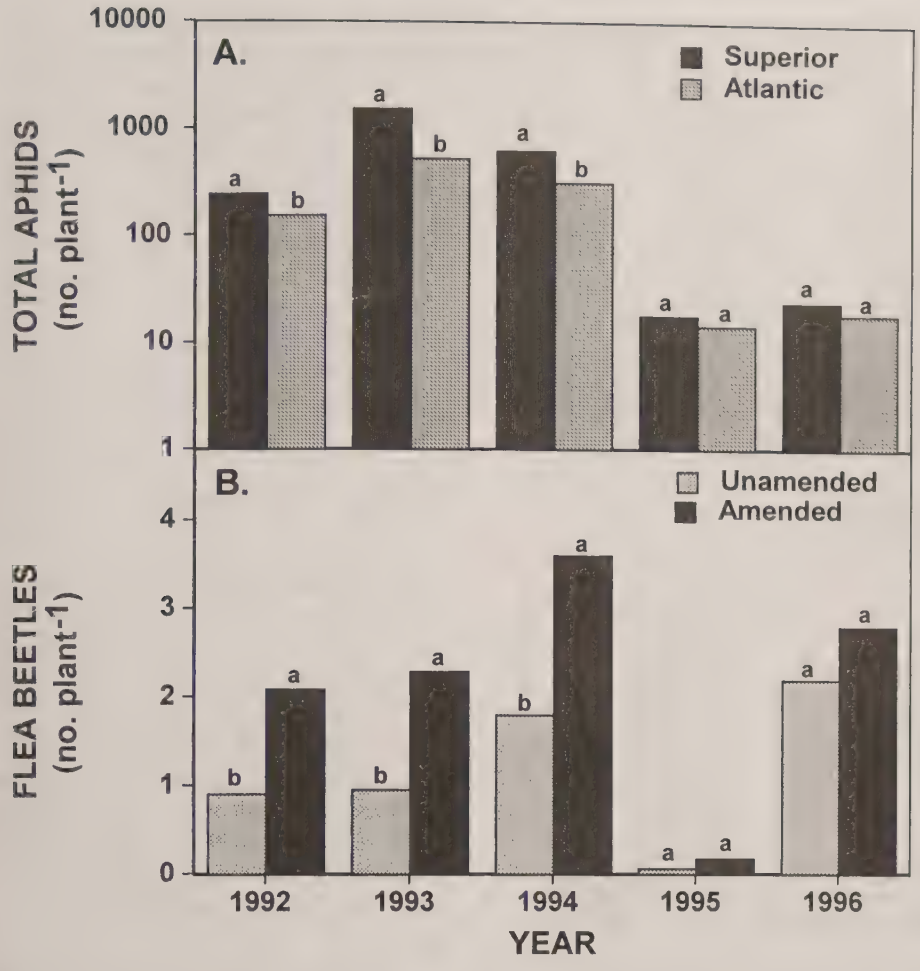

Fig. 3. Influence of potato variety on aphid density (A) and influence of soil management system on flea beetle density (B) in 1992 to 1996. Columns with the same letter indicate no significant differences between treatments in that year.

and increased its susceptibility to diseases. Disease ratings, however, are unavailable for this year. As experience was gained with the BIO system, inputs and management techniques were improved. Accordingly, it should be noted that the proportional difference between the BIO and CONV systems generally decreased over the years (39%, 41%, 4%, 28%, 20%, 15% for 1991-1996, respectively), although it was still substantial in 1996.

From the start of the experiment the amended system produced potato yields similar to those of the unamended system despite the fact that the amended system received less than half the amount of at-planting fertilizer (Tables 4 and 8). Although yields in the project were strongly linked to seasonal rainfall, yields of the amended system tended to be more stable, with lower variance among years (20.9 vs. 40.9). During the drier 1994 and 1995 seasons, amended potatoes had enhanced plant vigor and late-season canopy duration (data not shown) and produced significantly greater yields (13% in 1994 and 31% in 1995) than the unamended system. This effect may have been related to the greater organic matter content, better soil structure and therefore greater water supplying capacity, of the amended soils. In 1996, however, the amended system yielded less than the unamended system. Petiole analyses indicated that nitrogen became more limiting to yield in the amended system than in the unamended system during this season. Petiole nitrate-N concentrations were 1.77, 0.92 and 0.54% (dry weight basis) in the unamended potatoes vs. 1.13, 0.35 and 0.15% in the amended potatoes on July 18, August 1 and August 18, respectively. Differences were significant at the 0.01 level at all dates. The lower concentrations in the amended potatoes may have been due to low N availability from the compost and green manure in this system combined with early-season leaching resulting from relatively high May through July rainfall (Table 5).

Atlantic potato yields were either similar or significantly greater than Superior yields in every year (Table 8). More importantly, there were no interactions between potato variety and soil or pest management systems. These interactions may have been pronounced had one of the varieties been tolerant to key potato pests, such as late blight.

Total variable cost

Total variable costs are expressed as average annual costs per hectare for a full rotation, assuming that one-half hectare is in potatoes and one-half hectare is in the rotation crop. Costs for the two different potato varieties were almost always equivalent because the same price estimate was used for their seed; the only differences in cost between the two variety treatments were caused by differences in seeding rate. For this reason, costs are presented for other factors averaged over variety. The averages used in this economic discussion refer to the years 1993 through 1996 when the experiment was a full factorial of soil management and pest management systems.

The total variable cost for the RI system was, on average, 90% of that for the CONV system (Table 9). This was due to the fact that the RI system, which relies on higher pest thresholds and reduced rates of pesticides, incurred less than two-thirds the pesticide costs of the CONV system. The BIO system's average total variable cost was equivalent to that of CONV system, yet there were important differences in the breakdown of the pest control costs. Although the BIO system had higher total pest control costs (includes pesticides, spraying and mechanical control), it incurred only one-third of the weed control costs (includes herbicides, spraying and mechanical control) and two-fifths of the fungicide costs of the CONV system. The insect control costs of the BIO system (includes biological materials), however, were on average 3.4 times greater than those of the CONV system. Thus, high

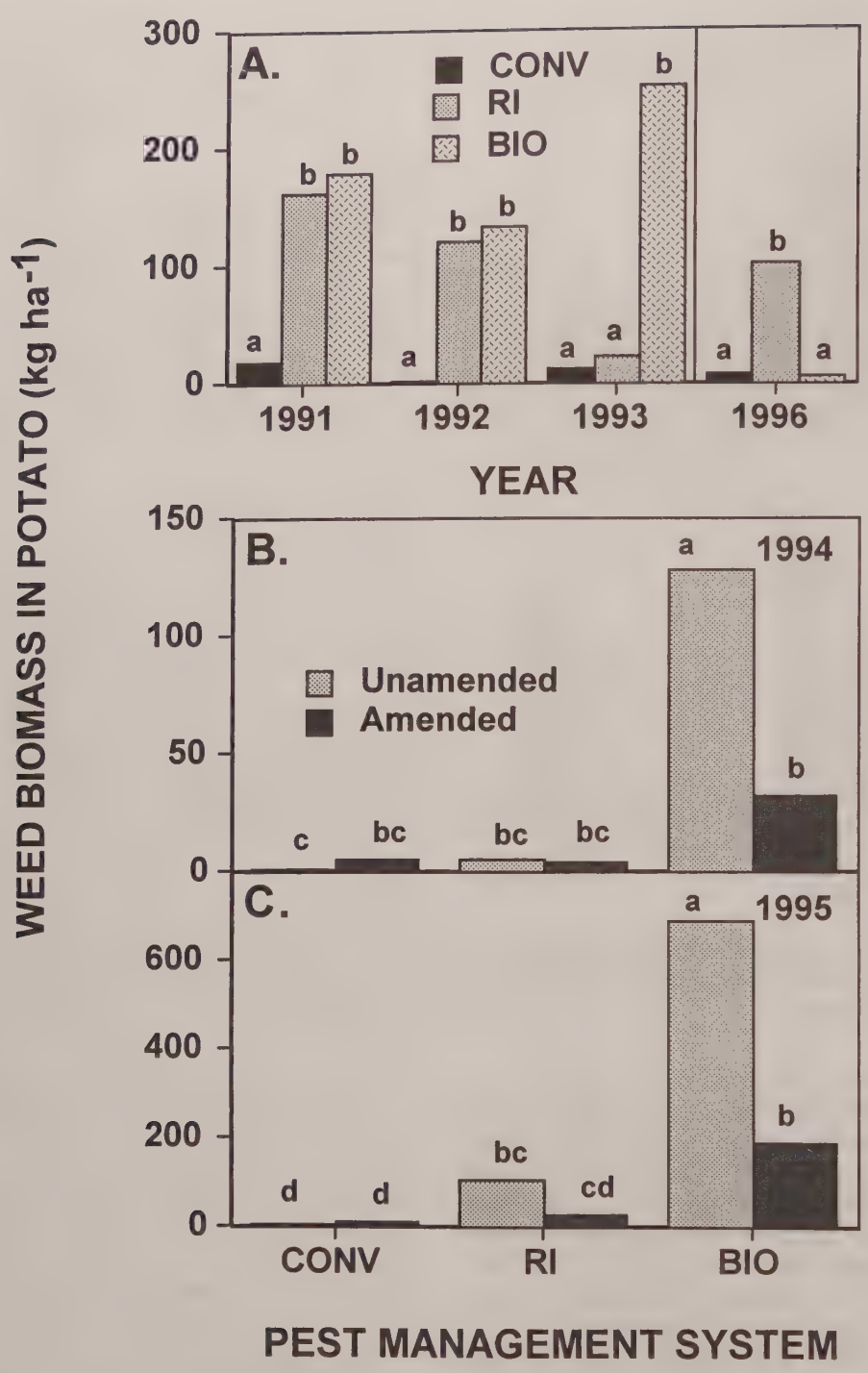

Fig. 4. Total above-ground weed biomass in potato (measured early- to mid-August) as affected by main effects of conventional (CONV), reduced input (RI) and bio-intensive (BIO) pest management systems in 1991 to 1993 and 1996 (A), and the interaction of pest management x soil management systems in 1994 (B) and 1995 (C). Columns with the same letter indicate no significant differences between treatments in that year. Adapted from Gallandt et al., 1998.

insect control costs appear to be responsible for the relatively high expense of the BIO system. Note, however, that the current cost calculations for the BIO system include an estimate for the cost of *Beauveria* and do not include the cost of the biocontrol predator *Perillus*. The actual total variable cost of this system would likely be different once these biocontrol products are fully commercialized.

The total variable costs for the amended system were substantially higher than for the unamended system (Table 9). While the amended system spent, on average, \$138 ha^{-1} (66%) less on fertilizer, it had a \$405 ha^{-1} average cost for compost and manure that the unamended system did not. The unamended system also benefited from barley returns which, on average, more than compensated for the cost of growing the barley/red clover rotation crop.

Returns over variable costs

RI was always the most profitable of the pest management systems because it had yields and returns equivalent to the CONV system but lower variable costs (Table 10). The RI system earned on average \$111 ha^{-1} (11%) more than the CONV system, yet only in 1992 was the difference between these systems significant. In 1993, all three pest systems had statistically equivalent returns over variable costs. In the other years, the BIO system was lowest due to significantly lower potato yields.

Changes in the price of pesticides had little effect on the magnitude of differences between the pest management systems. For example, a 100% increase in pesticide price (does not include "biorational" pesticides such as pyrethrum) increased the difference between returns over variable costs of the RI and CONV systems by 16% and increased the difference between the CONV and BIO systems by only 6%. The BIO system became as profitable as the CONV system, however, with a 19% price premium offered for BIO potatoes (\$65.36 Mg^{-1} vs. \$54.82 Mg^{-1} average price), which could be marketed as "low-spray."

Although the amended system had greater returns than the unamended system in every year except 1996, the greater returns were not high enough to offset the amended system's higher variable costs; therefore, the unamended system was consistently more profitable than the amended system (Table 10). The difference between the two systems decreased from 1992 to 1995, to the point of being insignificant in 1995, due to increasingly greater yields

Table 9. Average annual total variable costs of three pest management systems (averaged over soil management system and potato variety) and the soil management systems (averaged over pest management system and potato variety) for 1993-96. Whole rotation total variable costs are expressed as $ ha^{-1} assuming that one-half hectare is in potato and one-half hectare is in rotation crop.

	Pest management system[1]			Soil management system	
	CONV	RI	BIO	Unamended	Amended
Rotation crop	---------- Mg ha^{-1} ----------				
Seed	180	180	183	62	301
Fertilizer	35	35	35	69	0
Compost	42	42	42	0	86
Herbicides	1	<1	0	1	0
Field operations	67	67	62	96	32
Returns from barley	(143)[2]	(153)	(141)	(291)	0
Subtotal	182	171	181	(63)	419
Potato crop	---------- $ ha^{-1} of potato crop ----------				
Seed	514	514	514	514	514
Fertilizer	250	250	250	353	146
Compost and manure	321	321	321	0	642
Fungicides	203	119	104	141	141
Herbicides	121	52	0	57	57
Insecticides[3]	99	74	316	163	163
Field operations	405	380	378	375	403
Subtotal	1913	1710	1883	1603	2066
Whole rotation average	---------- $ ha^{-1} of whole rotation ----------				
total variable costs[4]	1048	941	1032	770	1243

[1] CONV = conventional; RI = reduced input; and BIO = bio-intensive.
[2] Numbers in parentheses are negative costs, i.e., revenues.
[3] Includes all biological control materials except *Perillus*.
[4] Equals total variable costs of rotation crop plus those of potatoes, divided by 2.

and concurrent reductions in costs for the amended system. In 1996, however, the unamended system produced greater yields and was substantially more profitable than the amended system. On average, the amended system's returns over variable costs were $346 ha^{-1} (or 34%) less than those of the unamended system.

These returns over variable costs calculations are based on compost and manure prices paid by the experimental farm. Actual potato producers, who may have access to organic amendments, could experience much lower costs. In central Maine, associations between neighboring potato and livestock operations exist, and are becoming more common, whereby the potato farm receives excess livestock manure for the cost of spreading it (T. Griffin, 1997, personal communication). Applying this scenario to our data would reduce the total variable costs of the amended system from $1243 ha^{-1} to $1100 ha^{-1}. The difference between the unamended and amended system return over variable costs would decrease to $203 ha^{-1}. Another cost-saving option would be to produce potato cull compost on farm, thereby reducing the cost of this amendment from $15.96 Mg^{-1} to $4.63 Mg^{-1} (Mallory, unpublished). The amended system's total variable costs would decrease to $1116 ha^{-1} and the difference in returns over variable costs would be $220 ha^{-1}. A combination of these two scenarios would drop the amended systems total variable costs to $973 ha^{-1} and the difference in returns over variable costs to $76 ha^{-1}. While the amended system is never as profitable as the unamended system by any of these scenarios, they do demonstrate that the costs experienced by a producer using amendments will depend dramatically on their particular situation.

Another aspect of the amended system that warrants examination is the rate of amendments used and their long-term effects. The goal of the experiment was to rapidly build soil organic matter and improve soil physical properties through the addition of high rates of amendments. Although this strategy worked, it is unlikely that it would be adopted by potato producers for economic reasons. Is it possible then to achieve and maintain the benefits of an amended system with more modest rates of amendments? This question is the focus of a current research project.

Conclusions

Results from the first six years of the Potato Ecosystem Project demonstrate the types of effects that improvements in soil quality may cause. Through the additions of manure, compost, and green manure, improvements in soil quality were observed within one to two years. Benefits to weed control efforts, tuber yield, and crop quality have already been realized and warrant additional research while benefits to insect and disease management are not clear. Lower profitability and phosphorus overloading have emerged as key concerns with the amended soil management system. Efforts to manage the major pests of potato have been successful using a reduced-input strategy that is more profitable than the conventional strategy. Several promising bio-intensive practices have been identified, but because of cost, additional research and development are necessary. The relative performance of the pest and soil management strategies tested was similar for two potato varieties that differed in stress tolerance. Critical questions remain:

Table 10. Pest management system, soil management system and potato variety effects on return over variable costs ($ ha^{-1})[1] for whole rotations.

	1992	1993	1994	1995	1996
Main effect averages			$ ha^{-1}		
Pest management system					
Conventional	1408b	894	1032a	373a	1260a
Reduced Input	1630a	931	1121a	467a	1373a
Bio-intensive	299c	768	356b	198b	991b
Soil management system					
Unamended	1317a	1139a	971a	373	1549a
Amended	907b	590b	701b	319	869b
Potato variety					
Atlantic	1084	951a	956a	516a	1223
Superior	1141	778b	719b	175b	1193
ANOVA results (by year)			p-values		
Pest management system	<0.01	ns	<0.01	<0.01	<0.01
Soil management system	<0.01	<0.01	<0.01	ns	<0.01
Variety	ns	<0.10	<0.01	<0.01	ns
Interactions	ns	ns	ns	ns	ns

[1] Assuming 0.5 ha of potato and 0.5 ha of rotation crop.

- Will improvements in soil quality lead to greater stability of potato yield and quality over years of varying weather conditions?
- What are the long-term effects of an amended soil management system on yields, insects, plant diseases, and weeds?
- How can an amended soil management system be maintained without overloading phosphorus?
- What is the duration of soil quality improvements and how can an amended soil management system be optimized for rate and frequency of application to improve its profitability?
- What are the long-term impacts of biocontrol agents?
- What is the whole-farm economic performance of alternative potato production systems, and what regional food or agricultural policy changes are required to improve the performance and sustainability of potato production in northern Maine?

These questions will be addressed in subsequent years of our study.

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Comparison of conventional and organic apple production systems during three years of conversion to organic management in coastal California

Sean L. Swezey, Matthew R. Werner, Marc Buchanan, and Jan Allison

Abstract. *Conventional and organic semidwarf Granny Smith apple production systems were compared during three years of conversion to certified organic management. Because of differences in fruit load with hand thinning compared with chemical thinning, apple tonnage was higher in the organic production system (OPS) in 1989 and 1991. The organic system was higher than the conventional system in number and weight of fruit per tree, but smaller in average fruit size. Using grower-received farmgate premiums of 38% (1990) and 33% (1991) for unsorted, certified organic apples, comparative cost accounting showed greater net return per hectare for the OPS. The OPS required higher material and labor inputs in all years.*

Greater terminal growth in the conventional production system (CPS) in 1991 was the only significant difference in growth indicators between systems. N was generally higher in leaf and new wood bark tissues in the CPS. P was generally higher in the leaf and new wood bark tissues in the OPS. No decline in yield was associated with increased weed biomass in the OPS. There was no difference in fruit damage caused by codling moth between production system treatments (codling moth granulosis virus and pheromone-based mating disruption vs. synthetic insecticide). In 1991, secondary lepidopterous pests (apple leafroller and orange tortrix) caused greater fruit scarring in the CPS. In all years, tentiform leafminers caused greater leaf damage in the CPS. Apple leafhopper density and leaf damage were greater in the OPS in 1990 and 1991.

Soil nutrient levels showed few significant changes during conversion to organic management. Soil bulk density and water holding capacity were useful indicators of changes in soil physical characteristics. Potentially mineralizable nitrogen and microbial biomass-C were more sensitive indicators of system change than total N or organic C. Two soil biological ratios, the respiratory ratio and biomass-C/total organic-C, were similar in the two production systems. Earthworm biomass and abundance increased in the OPS in the third year. The introduction of Lumbricus terrestris *into the OPS greatly increased litter incorporation rates.*

Key words: certified organic production, Granny Smith, pest management, codling moth, earthworms, soil respiration, soil fertility

By the year 2000, California will likely emerge as the second largest apple (*Malus* sp.)-producing state in the nation, with a 10% share of U.S. production and a total production of more than 450,000 t. The area in apples in California has increased 50% in the past two decades, to nearly 16,200 bearing ha.

Certified organic production, a small but growing share of statewide apple production, is an emerging technical and marketing alternative for California apples. Certified organic and transitional apple production has expanded to over 1,215 ha in California, according to calculations made from certification organization statistics and county agricultural commissioners[1] records. This area has more than quadrupled since 1989, when controversy surrounding detectable residues of daminozide (Alar) metabolites in apple products stimulated market interest in certified organic apples for both fresh market and processing fruit. If these trends continue,

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certified organic apple production could represent between 5 and 10% of the state total by the end of the decade.

Although conventional apple production systems in California are well documented technically (University of California, 1991; 1992), there is a lack of published research on management for the certified organic market, as presently defined by the California Organic Foods Act of 1990. There also is only a small but growing amount of general information regarding ecological dynamics when a conventional system is converted to pesticide-free or organic production (Maclellan, 1977; USDA, 1990; Prokopy, 1991; Caprile, 1992; Daly and Thomas, 1992; Vossen et al., 1992).

Organic production systems require significant modifications of pest management and soil fertility strategies during the transition to organic management (Altieri et al., 1983). However, it is rare to find published, long-term, well-characterized comparisons of organic and conventional systems during this conversion process. Many studies have been conducted to understand and compare arthropod communities in "abandoned," "unsprayed," or existing "organic" orchards with those in conventionally managed orchards (Hurlbutt, 1958; Maclellan, 1972; Thistlewood, 1991). These studies have shown that the undisturbed apple production agroecosystem can be rich in arthropods (Oatman et al., 1964; Hagley, 1974), and that broad spectrum pesticides disrupt naturally occurring biological control and skew diversity indexes toward pest species (Leius, 1967; Liss et al., 1986). The possible advantages of an arthropod-rich community coupled with certified organic inputs or amendments must be understood better to establish successful production systems.

The dynamics of soil and tissue nutrients must also be studied during the transition from conventional to organic production, both to learn how they affect yields and to understand the potential success and limitations of suitable soil fertility inputs for organic systems. For example, studies have shown that CO_2 is evolved faster by soils in organic apple orchards than conventional orchards, which suggests that nutrient use in organic systems is more efficient because of enhanced soil microbial activity (Helweg, 1988). Mycorrhizal associations (Plenchette et al., 1981) and soil invertebrates that incorporate surface litter (Raw, 1962) need further evaluation as potential amendments to organic systems. Improved management of decomposition and release of nutrients is important because many organic soil amendments, such as composted manures, do not make nutrients available as rapidly as the synthetic inputs commonly used in conventional systems. Increased soil biological activity may provide additional benefits by suppressing plant pests and disease (Stephens and Davoren, 1997).

To understand better the ecological and economic changes that occur during the conversion to organic management, in 1989 we established complete blocks of conventional and organic production systems in a commercial semidwarf Granny Smith apple planting. The study site was an established conventional apple orchard west of Watsonville, California. In 1990, the University of California's Sustainable Agriculture Research and Education Program and the Center for Agroecology and Sustainable Food Systems began a system-level study of the conversion to certified organic management to monitor potential yield-limiting factors during this process, such as soil characteristics, nutrient availability, and the abundance and impacts of insect pests and weeds. We expected to provide long-term biological and economic information that would help in evaluating the ecological and economic sustainability of certified organic apple production on the Central California coast. We report here the results of the first three years of organic conversion.

Materials and Methods

In April 1989, the grower-collaborator and the investigators established randomized complete blocks of conventional and organic replicates in a commercial farm, 8 km west of Watsonville, California (Werner, 1996). The organic and conventional treatments both consisted of four 0.32-ha replicates of semidwarf (MM.106) Granny Smith trees in their seventh growing season, planted in double rows (1994 trees/ha). Trees were approximately 3 to 4 m in pruned central leader height at the beginning of this observation period. Each replicate consisted of six double rows (54 trees per row) with a tractor aisle of 4.3 m between rows and a distance of 1.8 m between trees. Each double row was 1.2 m wide, and the trees were offset by 0.9 m within the double rows. The tractor aisle had a mowed grass cover, largely composed of rescue grass *(Bromus willdenowii)*.

These plots were narrower and smaller than the ideal for studying mating disruption by pheromones; we accepted this design because of management requirements and risk considerations on the part of the grower-collaborator.

The first transition year was 1989, and organic certification (CCOF, 1990) was obtained for the 1990 and 1991 crop seasons. The two treatments are designated as the conventional production system (CPS) the organic production system (OPS) for ease in description. Soil type was Elder sandy loam in the western portion of the site, intergrading to Conejo loam in the eastern portion. All plots had been sprayed, irrigated, and chemically thinned for three years before this study, and we assumed that all factors influencing initiation and set of fruit buds were similar among the plots.

The grower-collaborator was responsible for all certified organic and conventional management on the respective plots, and we verified these practices through close weekly contact with him during the season. Table 1 summarizes the production system treatments each year. Codling moth granulosis virus (CMGV) was obtained from Louis Falcon (Department of Entomology, University of California, Berkeley). Mating disruption pheromone dispensers were obtained from CONSEP Membranes Inc., Bend, Oregon.

All treatment comparisons, except the mulch trial (described below), were done with two-way analysis of variance for a randomized, complete block design, with appropriate transformations of non-normal data (Little and Hills, 1978). We used Duncan's Multiple Range Test for separation of means in the weed comparison. Student's t-test was used pairwise for comparing the tree yield and growth in mulched and unmulched treatments (Little and Hills, 1978).

Table 1. Production systems treatment summary, 1989-1991.

Month	Conventional System	Amount/ha	Organic System	Amount/ha
Jan	• dormant oil + insecticide spray (chlorpyrifos)	38-57 l 3.8 l	• dormant oil spray	38-57 l
Feb	• in-row herbicide spray (glyphosate) • calcium nitrate fertilizer application	3.5 l 85.1 kg N		
Mar	• oil-lime sulfur fungicide spray • mow aisle groundcover	38-95 l	• in-row hand weeding • mow aisle groundcover	
Apr	• lime sulfur fungicide spray • sulfur fungicide spray • in-row herbicide spray (glyphosate) • mow aisle groundcover • rodent baiting (''phostoxin pellets'') • snail baiting (metaldehyde 4%)	38-95 l 57-95 l 3.5 l 28.4 kg	• oil-lime sulfur fungicide spray • sulfur fungicide spray (3) • rodent trapping • mow aisle groundcover	38-95 l 57-95 l
May	• thinning spray (carbaryl) • irrigation (N, 54 ppm) • codling moth spray spray (chlorpyrifos) 1.5 tons	8.5 kg 100 mm 3.4 kg	• codling moth granulosis virus (CMGV) application (3) 1989-90 • codling moth mating 105 mg per dispenser, disruption codlemone application (1991) • hand thinning/snail removal • chicken manure compost application (2% N) • in-row weed cutting • calcium phosphate rock soil application (1990) • irrigation (N, 54 ppm)	1.5x1014 GIB 48.5 dispensers/ha 283.5 kg 100 mm
Jun	• mow aisle groundcover • foliar calcium nitrate applications (to control bitter pit) (15% N)	28.4 kg		
Jul	• codling moth spray (chlorpyrifos) • foliar calcium nitrate applications (15% N) • mow aisle groundcover • irrigation (N, 54 ppm)	3.4 kg 28.4 kg 100 mm	• CMGV applications (4) 1989-90 • codling moth mating disruption codlemone application (1991) • mow aisle groundcover • irrigation (N, 54 ppm)	1.5x1014 GIB 105 mg per dispenser, 48.5 dispensers/ha 100 mm

Plant development and yield

In 1990 and 1991, we counted flowers and leaf clusters on twenty permanent sample trees per replicate at full bloom. We assumed the baseline number of apple buds per replicate was similar at the beginning of our experiment, as all replicates had been exposed to similar conventional treatments since 1982. We measured average terminal leaf area, trunk circumference, and terminal growth at harvest on the same permanent sample trees, using the following methods. Five fully developed leaves were randomly selected from the midpoint of five different current-season terminal branches on each sample tree. The lengths of these terminal branches were measured. We placed leaves individually under a clear acetate strip, and any missing leaf area was traced and blacked out with a permanent marking pen. We then processed the destemmed leaves with a LICOR 3050A leaf-area meter to measure individual surface areas. The darkened areas on the acetate were also processed with the leaf-area meter to determine area lost to defoliators or disease as a fraction of the total leaf area (the sum of that present plus the missing area). Identical samples of fruit cluster leaves were taken and processed in the same manner in 1990 and 1991. We also examined leaves for presence of European red mite (*Panonychus ulmi*), tentiform leafminer blotches (*Phyllonorcycter* spp.), and apple leafhopper burn (*Typhlocyba pomaria*) (see "Key pest abundance" below). We measured the trunk circumference of each permanent sample tree at 30 cm from the soil surface at harvest each year. In all years, we measured yield at harvest (30 September-15 October) on these permanent sample trees by removing, counting, and weighing all fruit from each tree. Fruit size was determined by average weight of fruit in each treatment each year.

Plant nutrient accumulation

We sampled twenty trees from each replicate on seven dates (1990-1991). A total of ten leaves were collected from two terminal shoots per tree; each shoot was collected as representative of new season's wood, and a single sample of old wood was collected at the same time. Leaves

Table 1. Production systems treatment summary, 1989-1991 Continued.

Month	Conventional System	Amount/ha	Organic System	Amount/ha
Aug	• mow aisle groundcover • foliar calcium nitrate application (15% N)	28.4 kg		
Sep	• irrigation (N, 54 ppm) • mow aisle groundcover	100 mm	• irrigation (N, 54 ppm)	100 mm
Oct	• harvest • zinc sulfate application (1990)	28.4 kg	• harvest • zinc sulfate application (1990)	28.4 kg
Nov			• chicken manure compost application (2% N)	1.5 tons

were dried at 60°C, ground, digested in acid, and analyzed for total Kjeldahl N (Bremner and Mulvaney, 1982) and phosphorous (Sah and Miller, 1992). The wood was dried and the bark was stripped before digestion and analysis. All samples were pooled by replicate and analyzed at the UC Santa Cruz Agroecology Laboratory.

An additional sample of leaves taken in late July each year was dried and submitted to the University of California Cooperative Extension Analytical Laboratory in Davis, California. This midseason sampling is typically used by the grower-collaborator and extension personnel to evaluate nutrient status of trees each year. Macronutrients (N, P, K, Ca, Mg, and S) and micronutrients (Fe, Mn, Cu, Zn, and B) were measured in this annual sample, using the laboratory's standard methods. In 1990, the latter analysis showed that both the organic and conventional systems were below the critical standard for Zn. Zinc sulfate amendments were added to both production systems in October 1990. Zinc sulfate is allowed in organic production in California if leaf tissue analysis indicates Zn deficiency.

Apple litter incorporation

Apple leaves collected from the trees before leaf drop were air dried and placed under litter frames in the orchard. The wooden frames covered 0.25 m^2 and were 3 cm high, with chicken wire mounted across the top. We placed 90 g of dry apple leaves under each frame. To measure decomposition and incorporation, frames set out in February 1990 were collected in April 1990 and the remaining litter was weighed. We set out twice as many frames in January 1991, and collected half in April 1991 and the rest in May 1991. In January 1991, half the litter frames in the organic plots were inoculated with the earthworm species *Lumbricus terrestris* (40 adults per frame, equivalent to 160/m^2). *L. terrestris* was not introduced in the CPS because of potential interference with earthworm activity by synthetic herbicides and insecticides applied routinely for pest management.

Earthworm abundance and biomass

We sampled earthworms in each production system using the formalin expulsion technique (Satchell, 1971). Each sample area was 0.25 m^2, and two samples were collected in the row area of each plot. Sites where *L. terrestris* was released were purposely avoided during sampling times. We applied 4.5 liters of a 0.18% formalin solution twice, allowing 10 minutes to elapse after each application penetrated completely. After collecting all earthworms that surfaced, we hand-sorted the top 5 cm of soil for additional earthworms. Samples were returned to the laboratory in a cooler for identification, counting, and weighing. Weights were taken of live worms rinsed and blotted dry 24 hr after collection to allow for gut voiding. We collected samples in January 1990, monthly from December 1990 to May 1991, and in January and April 1992.

Soil microbial properties

We estimated microbial biomass using a modification of the fumigation-incubation method (Jenkinson and Powlson, 1976). For each replicate, a minimum of 20 soil cores were pooled to make one surface sample (0-10 cm), and four cores were pooled for the samples from 35-45 cm. These samples were stored at 2°C. Subsamples were oven dried at 105°C to determine soil moisture content. Water-holding capacity (WHC) was determined by weighing water-saturated samples before and after oven-drying. We fumigated subsamples by overnight evacuation in a vacuum desiccator containing 50 ml of distilled chloroform. Identical samples were left unfumigated as a control. Following fumigation, we inoculated all samples with 1 g of fresh soil, brought them to 55% WHC, then placed them in 0.95 liter glass jars containing 10 ml of NaOH. After 10 days at 25°C, NaOH was titrated to a phenolphthalein endpoint using HCl. Fresh NaOH was added to the control jars for a further 10 days of incubation followed by titration. We calculated biomass from the flush of CO_2 released from fumigated soils during day 0 to 10, minus the flush from control soils during day 10 to 20.

We evaluated CO_2 evolution from unfumigated control samples as a measure of microbial respiration, and calculated ratios of biomass-C/organic-C, and CO_2-C/biomass-C (respiratory ratio). Potentially mineralizable nitrogen (PMN) was estimated by measuring ammonium before and after a 14-day anaerobic incubation at 30°C, with PMN calculated as the difference (Waring and Bremner, 1964; Keeney and Bremner, 1966). Samples were collected at three-month intervals from April 1990 to July 1991.

Soil physical and chemical characteristics

Soil samples for these measurements were collected as described above. For measuring pH, dried samples were mixed in a 1:2 slurry with water. For analysis of macro- and selected micronutrients, air-dried samples were ground to pass a 2-mm sieve and shipped to the University

of California, Cooperative Extension Analytical Laboratory. Organic C was measured by $K_2Cr_2O_7$ reduction of organic C and subsequent spectrophotometric measurement (modified Walkley-Black: Nelson and Sommers, 1982). Electrical conductivity (EC) was measured with the saturated paste technique using an EC meter (Rhoades, 1982). Soluble Ca and Mg concentrations in the saturated paste extracts were measured by atomic absorption/emission spectrometry (Lanyon and Heald, 1982). Extractable phosphate was measured using $NaHCO_3$ extracts (Olsen et al., 1954). Total N was measured using the standard Kjeldahl procedure (Bremner and Mulvaney, 1982). Exchangeable K was measured in ammonium acetate extracts by atomic absorption/emission spectrometry (Knudsen et al., 1982). Zn and Fe were extracted from soil using DTPA, with subsequent determination by atomic absorption spectrometry (Lindsay and Norvell, 1978; Greenberg et al., 1985). Sulfate-S was estimated by atomic emission spectrometry after extraction with monocalcium phosphate (Schulte and Eik, 1988; Meyer and Kellar, 1992).

VA-mycorrhizal fungi

We collected pooled samples of tree roots by digging to 25 cm at eight random spots within the tree rows of each replicate and gathering upturned roots by hand. Roots were cleaned in water, and fine lateral roots cut to 1-cm lengths. Roots were cleared in 2.5% KOH (60°C, 16 hr), bleached in water and ammonium hydroxide, and stained with trypan blue (Koske and Gemma, 1989). Percentage colonization of roots by mycorrhizal fungi was assessed using the grid-intersect method (Kormanik and McGraw, 1982). Samples were collected at 3-month intervals from July 1990 to July 1991. Because the heavy presence of mycorrhizal fungi within the organic system might indicate a deficiency in soil P, the grower-collaborator decided to apply calcium phosphate rock to the OPS replicates in May 1990.

Key pest abundance

To monitor codling moths (*Cydia pomonella*), one new 10-mg codling moth pheromone lure was placed in a sticky wing trap hung on a tree at the midpoint of the third row of each replicate (replaced every 60 days). We replaced trap bottoms as needed. Sixty fixed, 15.2-cm wide b-flute corrugated cardboard tree-bands were placed on the trunks of 60 randomly selected trees per replicate in August, 30 cm above the soil surface, to monitor codling moth pupation and overwintering. Visual fruit damage was scored at harvest (30 September - 15 October each year) on the twenty permanent, whole-tree fruit yield samples to determine infestation rates of codling moth, fruit pests, and disease agents. At harvest, all fruits were visually evaluated for both skinworm (*Argyrotaenia citrana*) and codling moth damage.

In 1991, we established a standard weather shelter with a hygrothermograph to monitor orchard temperatures. We used codling moth pupae in cardboard bands placed in field emergence cages, pheromone trap captures, and sunset temperatures to initiate degree-day accumulation (UCIPM, 1991). The Statewide UCIPM IMPACT computer network was used to run the "BUGOUT" degree-day model for codling moth at the study site. Predictions generated by this model allowed effective timing of codling moth control in both production systems.

Weed species and biomass

Number, species, and biomass were measured twice yearly in each treatment to assess growth of winter (rainfed) and summer (irrigated) weeds. We sampled four 0.5-m squares per replicate between the double tree rows. After species identification, all aboveground biomass of weeds was removed, dried at 60°C, and weighed.

A woven polypropylene mulch (Dewitt Pro-5 weed barrier, 136 g/m^2) was applied in May 1989 to four tree rows in two OPS replicates. Four adjacent tree rows were maintained unmulched. All tree rows had been maintained weed-free by chemical and physical treatments before 1989. We evaluated the effect of this mulch on weed biomass and on tree growth and yield beginning in 1991. Yield from five randomly selected trees in each mulched row was compared to yield in an adjacent unmulched organic row, for a total of twenty mulched and twenty unmulched trees, all organically managed.

Production cost and income

We computed production costs using input budgets provided by the grower in a post-harvest interview. We used standard cost of production data (UCCE, 1988; Klonsky et al., 1994) for freestanding, semidwarf, Granny Smith apples estimated by University of California Cooperative Extension in Santa Cruz County to calculate baseline operating budgets for the first production year comparison (1989). The grower reviewed these estimates for accuracy. Because the treatments did not vary significantly over the three-year observation period, we added a 5% annual inflationary increase in operating costs over baseline for both production systems during 1990 and 1991. Yield and income were calculated directly

Table 2. Mean growth, yield factors and apple yields, 1989-1991.

	Conventional			Organic		
	1989	1990	1991	1989	1990	1991
Tree circumference (cm)	—	19.6	20.6	—	19.6	20.9
Upper crown terminal growth (m)	—	0.41	0.47*	—	0.38	0.36
Flower clusters/tree	—	199.2*	194.4	—	144.3	202.7
Apples per tree after thinning	102.4	88.1	108.1	174.7*	107.6*	67.4*
Yield (kg per tree)	21.1	17.0	18.1	27.8*	18.6	23.1*
Yield (metric tons/ha)	41.3	33.4	35.6	54.6*	36.3	45.2*
Weight per apple (kg)	0.21*	0.19*	0.17	0.16	0.17	0.14*

* indicates significant treatment differences between conventional and organic plots ($p<0.05$).

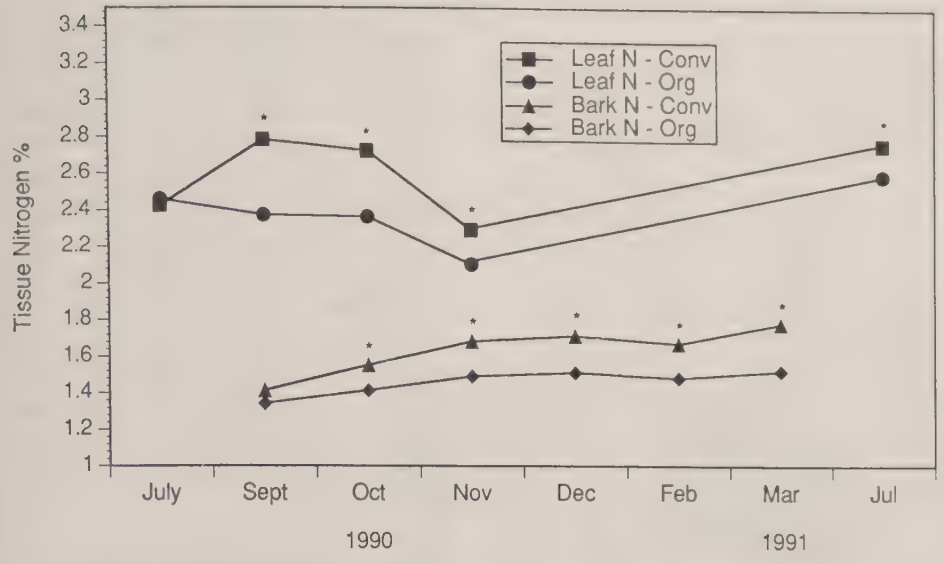

Figure 1. Fluctuations of N concentration in leaf and new wood bark over eight sample dates, 1990-91. * indicates significant differences ($p<0.05$).

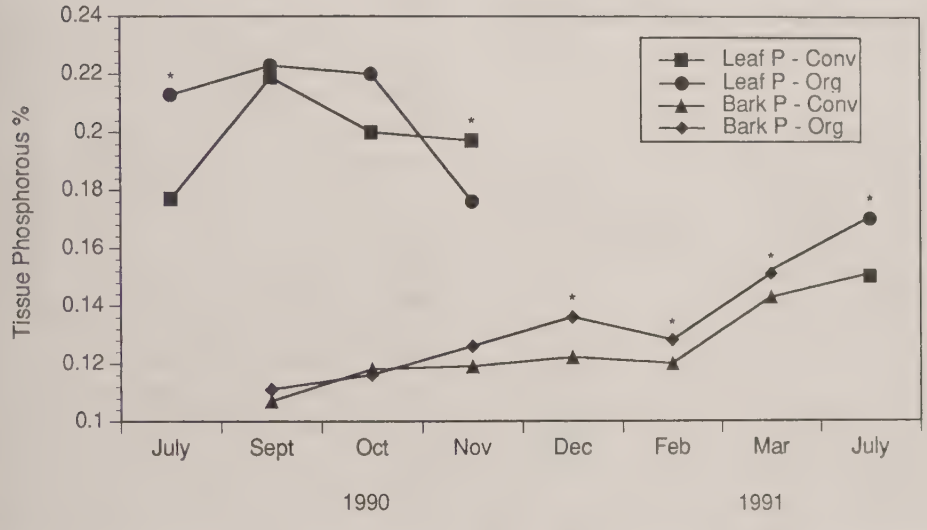

Figure 2. Fluctuations of P concentration in leaf and new wood bark over eight sample dates, 1990-1991. * indicates significant differences ($p<0.05$).

from observed values and seasonal averages for the unsorted tonnage sale price estimated by the grower.

Results

Plant development and yield

Initial terminal growth and tree girth were not significantly different between production systems at the end of 1990 (Table 2). During the same year, return bloom was greater in the CPS. In 1991, mean terminal growth was greater for CPS trees. Apple tonnage and fruit yields were greater in the OPS in 1989 and 1991, although this effect was probably due not to the OPS treatment, but to the decreased efficiency of the hand thinning used in the OPS. Because of the need to hand-thin the clusters in the OPS, significantly higher fruit loads were left on the trees for harvest, resulting in smaller apples. Early chemical thinning (with carbaryl) in the CPS consistently resulted in fewer apples per tree and larger size at harvest, but lower tonnage in 1989 and 1991. Since in both systems the production goal was to deliver apples to the fresh market, the absence of an organically acceptable chemical thinner was a significant problem.

Plant nutrient accumulation

N was generally higher in the leaves and new wood bark in the CPS (Fig. 1). In contrast, P in these tissues was generally higher in the OPS (Fig. 3). Although leaf N was similar in the July 1990 samples, by September it was higher in the CPS. During early leaf drop (November 1990) and the beginning of the next season (July 1991), leaf N concentration remained significantly higher in the CPS than in the OPS. N concentration declined before leaf drop in both systems. A similar trend was observed in leaf P, which increased before harvest and declined sharply before leaf drop. Although P was significantly higher in the OPS at the start of the 1990 season (July), by leaf drop (November 1990) P was higher in the CPS. Leaf P concentrations were again greater at the start of the next growing season (July 1991).

On the first sample date (September 1990), bark from new wood in the CPS had a higher N concentration than in the OPS, but was similar in P concentration (Figs. 1 and 2). The N and P content of new wood bark generally increased through the fall, declined slightly in winter, then increased again at budbreak (March 1991). The higher N content of new wood bark of CPS trees at budbreak in 1991 correlated with higher leaf N content in midsummer 1991. The higher P content in new wood bark of OPS trees at budbreak in 1991 also correlated with higher leaf P content in midsummer 1991.

Midseason leaf tissue samples collected by the grower each year showed that leaf N fell within the critical standards established by Cooperative Extension in both production systems in all three years (Table 3). Leaf P was consistently higher in the OPS. Leaf K concentration was significantly greater in the CPS in both the July 1989 and July 1991 samples. Ca leaf concentration was significantly greater in the CPS in both the July 1989 and July 1990 samples. In contrast, Ca was significantly greater in the OPS during the July 1991 sample.

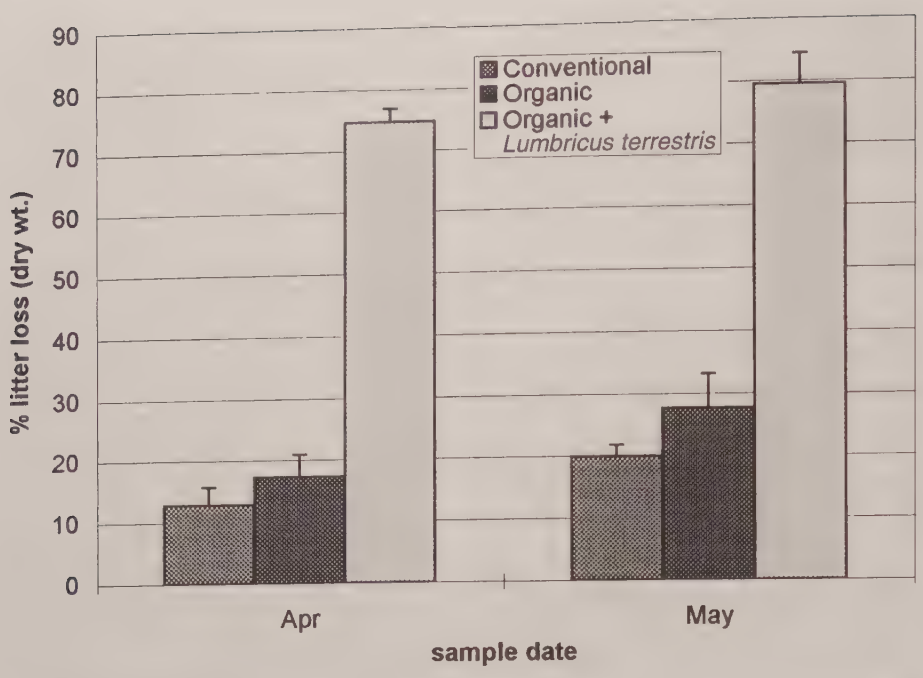

Figure 3. Disappearance of apple leaf litter from soil surface (means and SE). Litter was placed on soil surface in January, and collected in April and May 1991.

Table 3. Annual (late July) leaf nutrient analysis, 1989-1991.

	Conventional			Organic			Critical
	1989	1990	1991	1989	1990	1991	Standard[1]
			Macronutrients (%)				
N	2.23*	2.38	2.71*	2.14	2.38	2.60	2.0 - 2.4
P	0.14	0.18	0.16	0.18*	0.21*	0.17	0.1 - 0.3
K	1.14*	1.12	1.06*	1.04	1.15	0.94	1.2
Ca	1.95*	0.96*	0.86	1.59	0.70	1.01*	1.0
Mg	0.38	0.21	0.25	0.33	0.17	0.29	0.25
			Micronutrients (ppm)				
B		27.5	25.8		38.5*	26.8	25 - 70
Zn		13.8	13		13.3	14.8	18
Mn		45.8	52		37.5	47.3	20
Cu		4.9	4.7		4.9	6.3	4

[1] Critical nutrient levels based on UC Cooperative Extension guidelines (UCCE, 1992). * indicates significant treatment differences between conventional and organic plots ($p<0.05$).

Apple litter incorporation

In the first year of observation (1990), an average of 20% apple litter was incorporated in a two-month period in both production systems. In 1991, *L. terrestris* significantly increased incorporation to approximately 80% in the subplots where it had been introduced (Fig. 3). Less than 30% was incorporated in the organic and conventional systems without *L. terrestris*.

Earthworm abundance and biomass

Initially, two species of earthworm, *Aporrectodea caliginosa* and *Microscolex dubius*, were present in both production systems. *L. terrestris* was retrieved from some organic plots in 1992, following introduction the previous year. In the January 1992 sample, 1 of 197 earthworms collected from the OPS tree rows was *L. terrestris*, which accounted for 3.2% of the biomass. In the April 1992 samples, 1 of 10 earthworms collected was *L. terrestris*, accounting for 25% of biomass.

Peak activity of earthworms occurred between January and April. The earthworm density of almost 200/m^2 in organic tree rows from the January 1992 sampling was nearly 2.5-times greater than in the conventional tree rows. Statistically significant treatment differences in earthworm density and biomass (Fig. 4) occurred in the tree rows in January and April 1992. No earthworms were retrieved from conventional plots during the April 1992 sampling.

Soil microbial properties

Soil microbial biomass C from 0 to 10-cm samples was significantly higher in the OPS tree rows during October 1990, April 1991, and July 1991 (Fig. 5). Microbial biomass was generally lower at 35-45 cm (30 to 50 mg C/100 g soil), and no clear differences were found between management treatments or locations at this depth.

Microbial respiration, as measured by CO_2 evolution, was greater in surface soils collected from the tree rows in the OPS than in the CPS (Fig. 6). Differences were statistically significant in April 1990, July 1990, and July 1991. No differences between systems were seen in microbial respiration at a depth of 35-45 cm.

The respiratory ratio tended to be greater in soils from the OPS than the CPS, but statistical differences between production systems were detected only in April 1990 (data not shown). This ratio, not including a peak for both CPS and OPS (17 and 20% respectively), generally averaged about 5%. Biomass C/organic C averaged about .02, with no significant differences between systems.

PMN was measured for only three of the six sampling dates. It was significantly greater in the organic plots during January and April 1991 (Fig. 7).

Soil physical and chemical characteristics

Soil bulk density was lower in the OPS plots on two of the six sample dates (Fig. 8). There were no significant differences

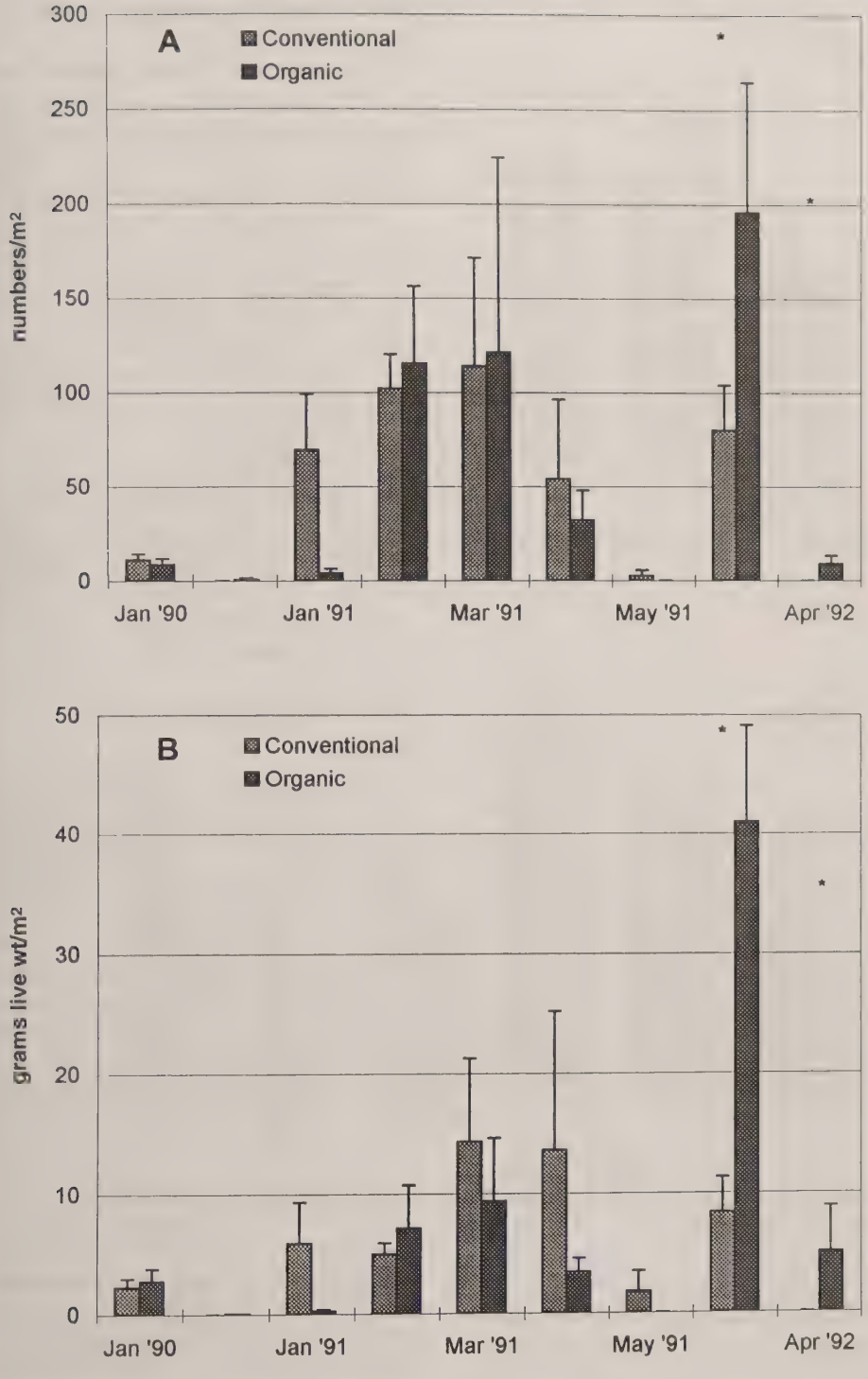

Figure 4. Resident earthworm abundance (A) and biomass (B) in tree rows during 1990-1992, estimated using formalin expulsion technique. Error bars represent standard error of the population. Note that X axis is noncontinuous. * indicates statistically significant treatment difference for that sample date based on two-way ANOVA results ($p<0.05$).

between production systems in soil moisture content at either sample depth (data not shown). Soil moisture fluctuated seasonally; peaks occurred during the winter rainy season, and moisture content decreased below 15% in the summer and fall. WHC varied considerably at both soil depths. At the surface, it tended to be greater in the organic plots (Fig. 9), with statistically significant differences in April 1990 and January 1991. WHC at 35-45 cm also tended to be greater in the organic plots, although differences were statistically significant only in April 1991 (data not shown).

Total soil organic C was not different between the two production systems at 0-10 cm (data not shown). At 35-45 cm, organic C was significantly higher in the OPS during January, April, and July 1991. There were no significant differences in soil nutrient concentrations between production systems in May 1990 and July 1991 (Table 4).

VA-mycorrhizal fungi

Mycorrhizal colonization tended to be greater on apple roots in the OPS. Statistically significant differences were detected on all sample dates except April 1991 (Fig. 10).

Key pest abundance

The production systems were continuously subjected to two generations of codling moth, reflected in two male flight peaks captured in pheromone traps (Fig. 11). The first peak represented emergence of the overwintering generation (April); the second represented the first in-season generation (July). In all years the pheromone trap catches showed male flight dynamics as two discrete peaks of activity. In 1991, the male flight periods generally agreed with BUGOUT computer model predictions, which allowed mating disruption pheromone treatments to be timed to correspond more closely with adult flight and egg-laying (Fig. 12). Significantly more males were captured by codling moth traps and post-harvest colonization of tree bands was greater in the organic (CMGV-treated) system in 1990 (Table 5). However, this trend did not continue in 1991, when pheromone-based mating disruption was used for codling moth control.

Codling moth damage to harvestable fruit did not differ significantly between production systems (Table 6). In 1991, however, the CPS had significantly more "skinworm" feeding damage caused by *Argyrotaenia citrana* (orange tortrix) and *Pandemis pyrusana* (apple pandemis). No significant differences were detected in leaf area removed by defoliators in the fruit or upper terminal leaves in any year.

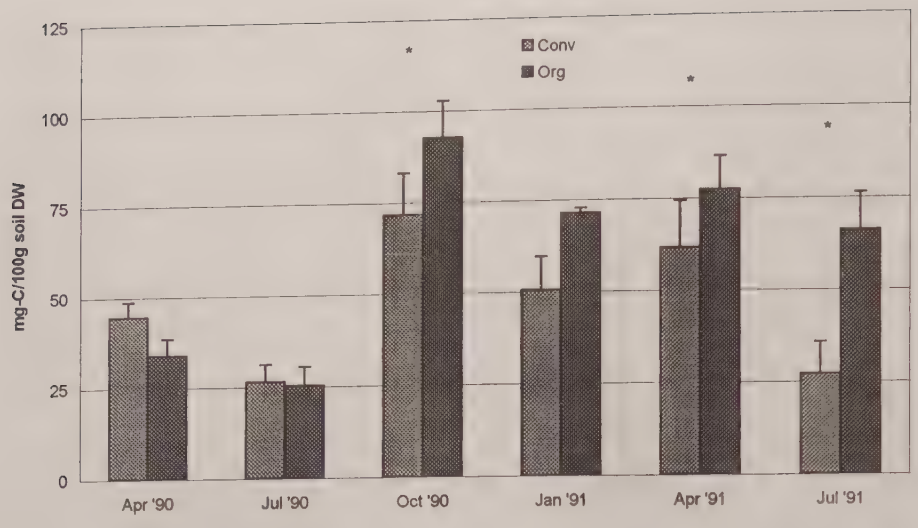

Figure 5. Soil microbial biomass in surface 0-10 cm, 1990-1991. * indicates significant treatment differences at p<0.10.

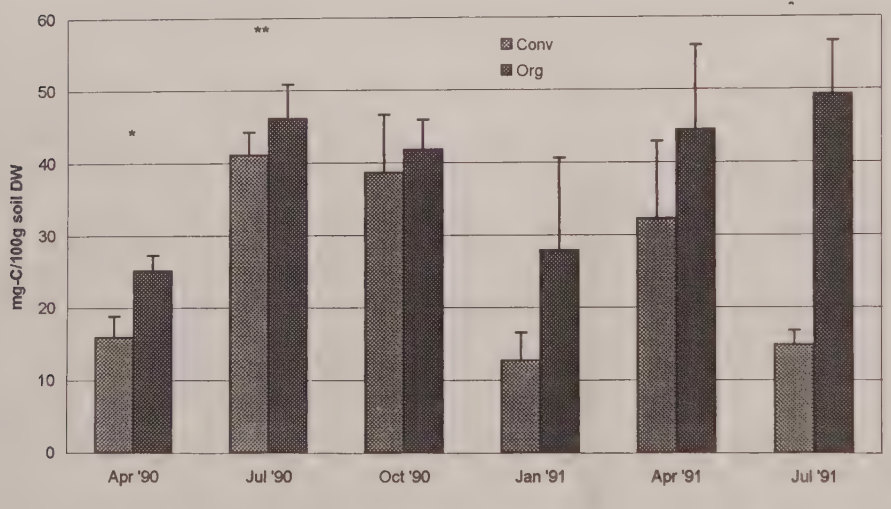

Figure 6. Microbial respiration from soils at 0-10 cm, 1990-1991. * indicates significant treatment difference at p<0.10, ** at p<0.05.

Tentiform leafminer blotches on fruit clusters were significantly greater in the CPS in all years. Feeding damage or "burn" from white apple leafhopper (*Typhlocyba pomaria*) was significantly greater in the OPS in 1990 and 1991. Other homopterous pests, such as aphids, occurred only sporadically during the spring in each growing season. Subeconomic densities of European red mite, powdery mildew, and apple scab were found on leaf samples at harvest in both production systems, with no significant differences detected at these low levels. No insecticides were applied for these secondary pests in the CPS in any year.

Weed species and biomass

In the double tree rows, unmulched organic plots (subject to twice-yearly spring and fall hand weeding) had the highest weed biomass on all sample dates. Because of a hand weeding immediately before sampling, there was no significant difference between the unmulched organic and conventional treatments in October 1991 (Table 7). The difference in biomass between the systems was greater in spring than in fall.

In summer 1990, the two systems were similar in the species composition of the weed understory, including redroot pigweed (*Amaranthus retroflexus*), field bindweed (*Convolvulus arvensis*), and several grass species. In April 1991, grasses such as soft chess (*Bromus mollis*) and rescue grass were abundant in the OPS. In April 1992, field bindweed and white clover (*Trifolium repens*) were the most numerous species in the CPS, while rescue grass had excluded nearly all other species from the OPS.

Although weed biomass in the tree row was significantly greater in the OPS than in the CPS, there were no significant differences in apple crop yield, tree girth, or mean terminal length between mulched and unmulched organic treatments over a three-year period (Table 8).

Production costs and income

In the transition year (1989) and the first two certified organic years (1990 and 1991), the OPS used 9% more labor and had a 17% higher materials cost (Table 9). Net return ($/ha) was higher in transitional organic production because of a higher tonnage of smaller apples from this lightly hand-thinned production system in 1989. The certified OPS in 1990 and 1991 showed increasing net profits when compared with the CPS because of higher tonnage and a grower-estimated premium of $84/ton on the organic market. Granny Smith is commonly sold by the field ton, and the grower-collaborator estimated the ungraded tonnage price each year. Oversupply of Granny Smith apples in the conventional market has led to low or negative net returns on conventional orchards that yield less than about 44 metric tons/ha in the coastal growing region.

Discussion

Plant development and yield

Tonnage of apples and growth indicators of apple trees were not adversely affected by certified organic management practices; in fact, the OPS produced significantly greater tonnage in both the transitional year (1989) and a fully certified year

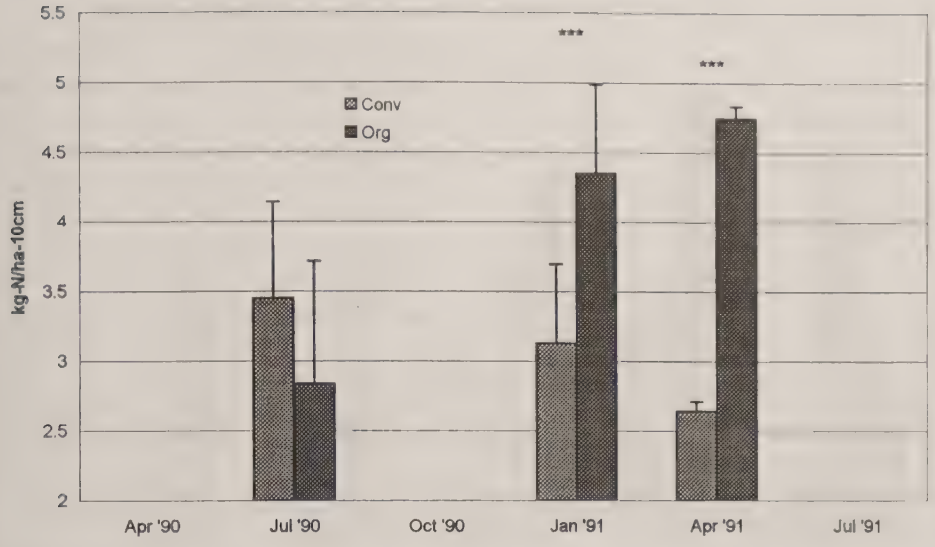

Figure 7. Potentially mineralizable nitrogen (PMN) in soil at 0-10 cm, 1990-1991. * indicates significant treatment differences at p<0.01.**

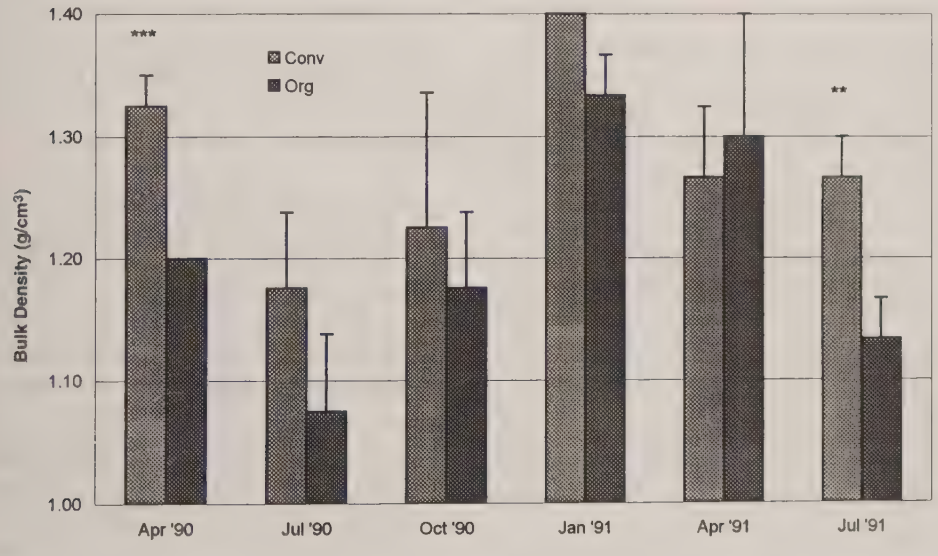

Figure 8. Soil bulk density at 0-10 cm, 1990-1991. ** indicates significant treatment differences at p<0.05; * at p<0.01.**

(1991). We did not thin the fruit in the two production systems to equivalent levels at the beginning of the observation period, so that it is difficult to ascribe the yield increase to the OPS treatment. However, this is the first comparison of its type in California, and is noteworthy for the preliminary success of conversion to certified organic practices and the lack of intrinsic yield reduction. Many aspects of this response require further research and observation to improve both our explanatory ability and the potential economic performance of the OPS, including size response to organic treatments when apple load is more efficiently controlled in the OPS.

Because no chemical thinning agent is approved for use in certified organic production in California, additional hand thinning is a major labor expense, adding 49 hr/ha. Though we attempted to equalize the number of apples left on trees in the two production systems, it was difficult to obtain consistency within hand and chemical thinning themselves. Hand thinning of fruit clusters still left the OPS with fruit loads higher by 70%, 22%, and 55% in 1989, 1990, and 1991, respectively. This higher load at harvest resulted in smaller apples on average. Early chemical thinning (with carbaryl) in the CPS and supplemental hand thinning consistently resulted in fewer larger sized apples per tree but lower tonnage at harvest. The increased fruit load in the OPS did not harm return bloom or yield. To understand better the relationships among apple tree yields, mean apple weight, and nutritional requirements of trees in both the OPS and CPS, further studies must be conducted in which thinning regimes are standardized.

Plant nutrient accumulation and VA-mycorrhizal fungi

Although the increased fruit load in the OPS did not harm return bloom and yields, we speculate that N and P content of tissue was directly affected. The generally lower N content of leaf and new wood bark tissue in the OPS trees may be due to a greater demand on N reserves. Without differences in soil fertility, and assuming similar N content in fruit, this demand could be caused by higher fruit load or weed competition in the OPS. Granny Smith apples, especially on the central coast, require higher soil N than most other apple varieties (UCIPM, 1991). N level can affect fruit yields, size, and color of Granny Smiths. It is an important nutrient to monitor during the conversion process because higher yields (due to the expense and difficulty of hand thinning) may increase N demand.

The addition of calcium phosphate rock to the OPS in May 1990 makes the higher P content in OPS leaf tissue difficult to interpret. Assuming that P content of fruit is similar in the two systems, a greater demand in the OPS trees would be expected. This higher P demand may be masked by the fact that more P was available. Leaves and new bark in the OPS were higher in P when the nutrient comparisons began. By the end of the 1990 harvest (November), P content was significantly lower in the OPS leaf tissue, then increased significantly over CPS levels in July 1991. These fluctuations, in the context of an application of phosphate rock, show that P is an important amendment in organic apple orchards that must be monitored to avoid deficiencies.

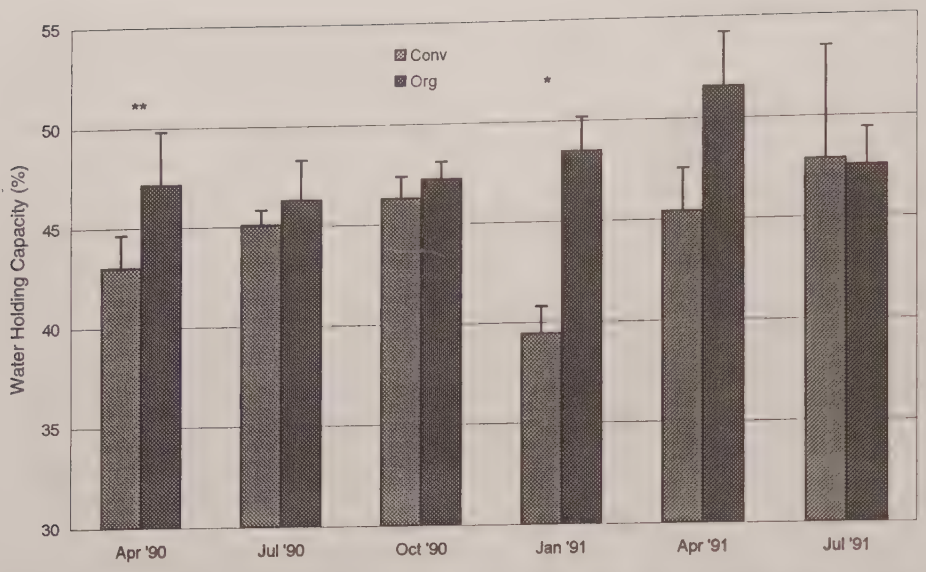

Figure 9. Water-holding capacity of soil at 0-10 cm, 1990-1991. * indicates significant treatment difference at p<0.10, ** at p<0.05.

Table 4. Soil nutrient concentrations (mean and standard error) in conventional and organic production systems.

	Conventional		Organic	
	Mean	SE	Mean	SE
	---------- May 1990 ----------			
(dS/m)	3.55	0.53	2.85	0.41
Ca (meq/l)	20.3	2.6	19.6	4.1
Mg (meq/l)	9.1	1.5	9.3	2.9
SO_4^{2-} (est ppm)	171.8	27.7	231.5	48.3
N (%)	0.200	0	0.200	0.041
P (ppm)	17	9	23	15
K (ppm)	601	133	460	95
Zn (ppm)	17.5	1.9	17.8	1.5
Fe (ppm)	87.0	22.7	82.3	24.3
	---------- July 1991 ----------			
EC (dS/m)	1.13	0.14	1.47	0.51
Ca (meq/l)	6.1	1.2	9.6	3.9
Mg (meq/l)	3.1	0.8	4.2	1.3
SO_4^{2-} (est ppm)	63.0	9.2	112.0	39.4
N (%)	0.200	0.029	0.167	0.033
P (ppm)	76	10	70	21
K (ppm)	567	126	523	114
Zn (ppm)	16.8	3.8	16.6	0.2
Fe (ppm)	70.0	2.0	68.3	6.8

The greater colonization by VA-mycorrhizal fungi within the OPS is important, as it has been found to increase the uptake of P by apple tree roots (Plenchette et al., 1981; Koch et al., 1982) and other systems (Linderman, 1988). Atkinson (1983) found higher leaf P in apple trees grown in grassed plots than in herbicide-treated plots. He speculated that a high root density of mycorrhizal grasses may enhance this P uptake, as the likelihood of root contact between apple trees and grasses may increase colonization of apples by VA-mycorrhizal fungi.

Foliar calcium nitrate was applied annually in the CPS to prevent the fruit disorder called bitter pit. Calcium amendments are available to counter bitter pit in organic systems, but the grower-collaborator had not had problems with bitter pit in the past and did not add this preventive amendment to the OPS. Although no bitter pit problems were seen in either system, our study showed that the addition of foliar calcium nitrate did significantly increase the amount of tissue Ca in the conventional system in two of the three monitored years. We suggest that tissue concentrations of Ca be routinely monitored and that amendments be applied as needed in organic production systems.

K was not applied in either production system. K concentrations were significantly lower in the OPS in two of the three monitored years. The grower-collaborator did not consider these differences to be serious. K concentration should be monitored and amendments should be added to counter possible deficiencies, with attention to possible effects on Ca uptake.

Apple litter incorporation and earthworm abundance

In the 1990 surveys, both the OPS and the CPS lacked soil invertebrates that could incorporate a significant amount of surface organic matter. The two earthworm species originally present in the orchard (*A. caliginosa* and *M. dubius*) are endogeics, species that burrow and feed in the subsurface mineral soil (Lee, 1985). Soil incorporation of surface-applied organic amendments such as compost is a desirable function of incorporator species. Incorporation of apple litter also can help reduce inoculum levels of organisms that cause fruit rot (*Phytophthora syringae*) (Harris, 1979) and apple scab (*Venturia inaequalis*) (Raw, 1962), the latter a fungus that overwinters on leaf litter and is transmitted to new foliage during spring rains (Hirst and Stedman, 1962).

During the second year, we introduced *L. terrestris* to test its effect on litter incorporation and its ability to establish a population in the OPS. This species is described as an anecic earthworm because it builds permanent vertical burrows and feeds by dragging organic materials from the surface into its burrows (Lee, 1985). Daly et

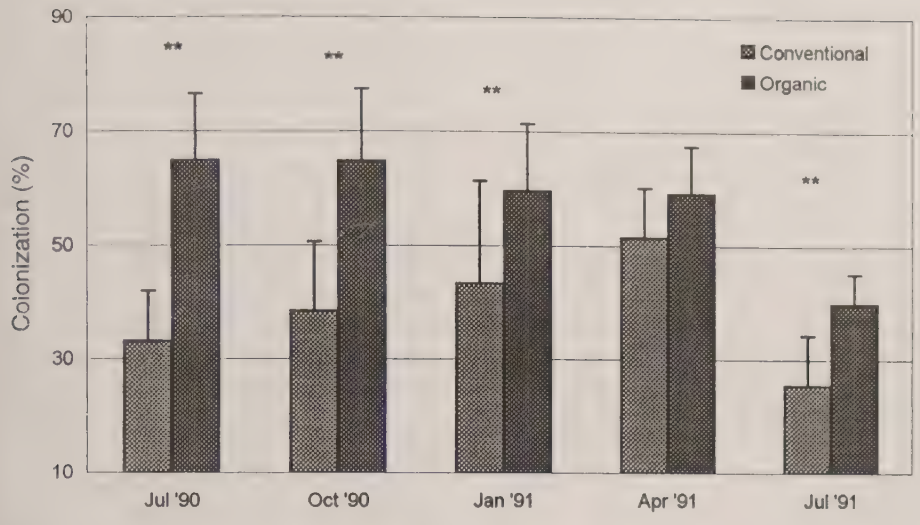

Figure 10. Percent colonization of apple roots by vesicular-arbuscular mycorrhizae, 1990-1991. ** indicates significant treatment difference at p<0.05.

Table 5. Codling moth life stage monitoring, 1989-1991.[1]

	Conventional			Organic		
	11/89	**11/90**	**10/91**	**11/89**	**11/90**	**10/91**
No. of bands infested	3	4	0	7	11	4
No. of codling moth larvae in overwinter bands	3	5	0	14	32*	4
% of bands colonized	2.5	5	0	5.8	13.8*	1.6
No. of accumulated male moths per pheromone trap (total seasonal)	12	13.5	8	19	22*	10.5

[1] 120 bands/treatment in 1989; 80 bands/treatment in 1990; 240 bands/treatment in 1991.
* indicates significant treatment differences between conventional and organic plots (p<0.05).

Table 6. Insect-caused defoliation and fruit damage, 1989-1991.

	Conventional			Organic		
	1989	**1990**	**1991**	**1989**	**1990**	**1991**
Area/leaf (cm^2) (fruit clusters/terminals)	21.7 (31.2)	20.6 (34.2)	21.5 (32.1)	21.4 (32.9)	17.9	18.7
Leaf area removed/leaf (%) (terminals)	3 (0.6)	0.6 (5.6)	0.5 (0.3)		3 (4.6)	0.7 (1.3)
Leaves with tentiform leafminer blotch (%) (fruit clusters)	12*	33*	18*	5	23.3	13.3
Leaves with leafhopper burn (%) (terminals)	—	15.5	2 (1)	—	63.3*	54 (52.3*)
Fruit damage by skinworms (%)	—	1.5	6.3*	—	1.1	1.2
Fruit damage by codling moth (%)	2.1	0.8	0.4	1.5	1.3	0.8

* indicates significant treatment differences between conventional and organic plots (p<0.05).

al. (1991) estimated that each mature *L. terrestris* buried about 20 apple leaves per season in an organic orchard in New Zealand. They estimated that a population of 20 worms/m^2 would be required to bury the entire leaf-fall in the observed orchard. We found that *L. terrestris* significantly increased the amount of litter incorporated in spring 1991. This species could help reduce tree disease inoculum and enhance litter incorporation and decomposition in organic production systems.

Earthworm activity in the orchard corresponded to the rainy season, which in coastal central California falls roughly between November and April. The higher density in the OPS plots in January 1992 may have been a response to the cumulative effects of fertility and weed management practices. Composted manures used in the OPS can increase soil organic matter and provide food for earthworms. Increased growth of annual weeds in the OPS in a sense is an intercrop that provides additional organic matter and alters habitat by shading the soil surface. There may be an ecological trade-off between the reduction of weeds by hand removal or mulching and the promotion of introduced incorporators. Pesticide use in conventional production systems may reduce earthworm populations. Potter et al. (1990) showed that chlorpyrifos and carbaryl reduced earthworm biomass about 30 and 70%, respectively, in a turfgrass system.

We did not repeat the litter incorporation study in 1992. However, signs of surface deposition of casts and incorporated litter in January 1992 showed that *L. terrestris* was still active. Formalin expulsion samples over inoculation spots yielded both adults and juveniles, showing that reproduction had occurred. One adult was found 10 m from the nearest inoculation spot, which shows the potential for dispersal in the orchard. The introduction of *L. terrestris* successfully increased the functional and species diversity of the earthworm fauna in the OPS.

Soil microbes, organic matter, and nutrients

In this study, microbial biomass C provided a more sensitive indicator of system change than either total N or organic C.

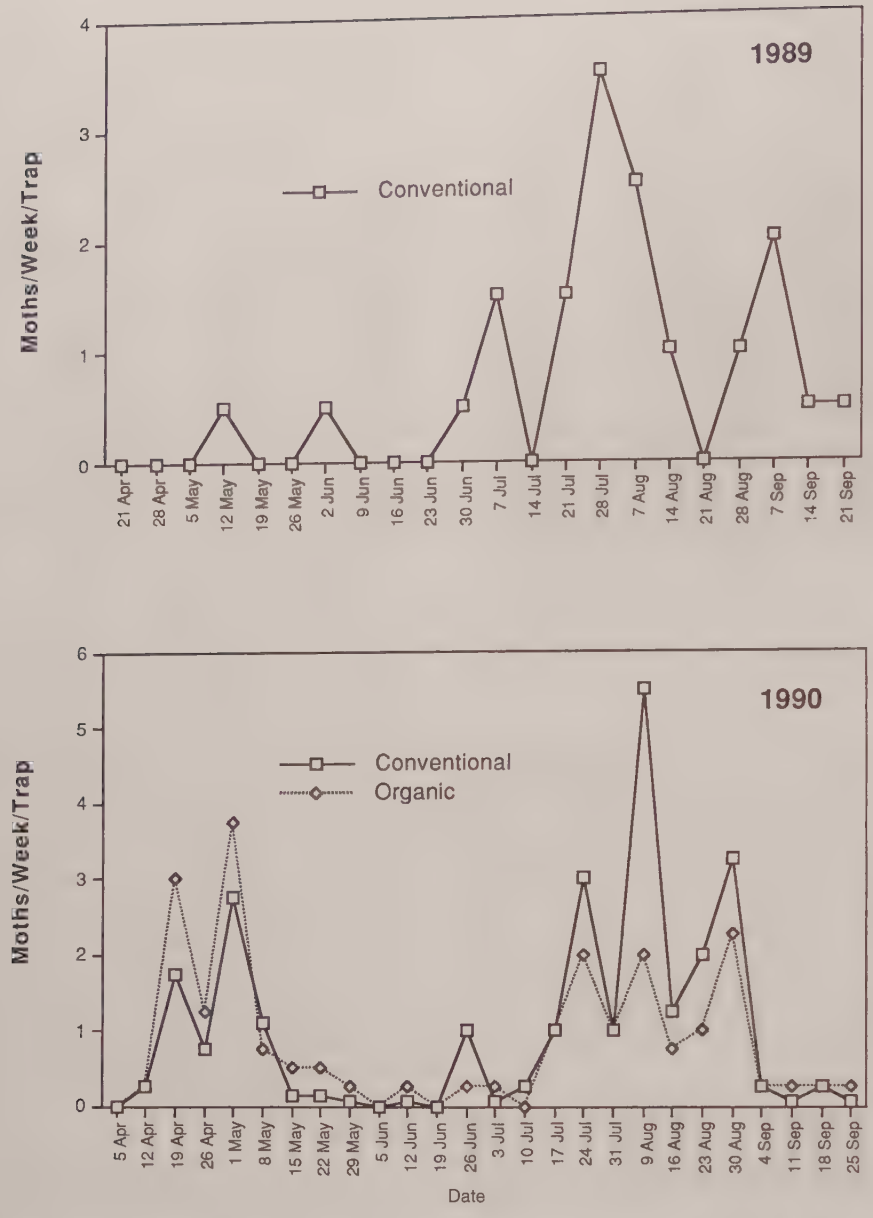

Figure 11. Mean weekly codling moth male capture in sticky wing traps. Rider conversion study, Watsonville, CA, 1989-1990.

Microbial biomass typically responds more quickly to management changes than soil organic carbon (Carter, 1986). Increased microbial biomass is an indicator of C accumulation, because a larger microbial biomass can produce stable forms of organic C. The soil biomass tends to increase under management systems that increase organic matter inputs, decrease physical disturbance from tillage, or reduce synthetic chemical inputs (Bolton et al., 1985; Powlson et al., 1987; Anderson and Domsch, 1989; Haines and Uren, 1990). Microbial biomass C may be seen as stored energy for microbial processes, and as such may represent actual or potential microbial activity (Rice et al., 1996). The soil biomass is an important source and sink for nutrients. This can be a useful indicator, especially in organic production systems, where fertility is based on organic matter management.

The ratio of microbial biomass C to total soil organic C has been suggested as a sensitive indicator of soil organic matter changes (Sparling, 1992), partly because the ratio will normalize some of the variability caused by temporal fluctuations in microbial biomass (Rice et al., 1996). There were no significant treatment differences in the current study, other than a greater value for the conventional plots on the first sample date. Reported ratios of biomass C to organic C range from 0.027 to 0.070 (Anderson and Domsch, 1989). In field experiments in temperate regions of Europe, long-term monoculture plots tend to equilibrate at ratios of 0.018 to 0.023 (Brookes et al., 1984; Anderson and Domsch, 1989), while crop rotations tend to equilibrate at higher microbial biomass levels, for average ratios of 0.025 to 0.033 (McGill et al., 1986). The ratios in the current study fell within the reported ranges, with values from the tree row similar to those reported for monocultures.

Microbial respiration tended to be greater in the organic plots. Other comparisons of conventional and organic orchards also have found increased microbial respiration under organic management (Helweg, 1988). However, increased respiration rate does not necessarily indicate improved soil quality. Because microbes are involved primarily in the decomposition of organic materials, increased microbial respiration may also indicate a potential for net loss of C (Parkin et al., 1996; Rice et al., 1996). The respiratory ratio, also known as metabolic quotient or qCO_2, is calculated from respiration per unit of microbial biomass (Turco et al., 1994). The ratio tends to be higher in stressed ecosystems (Insam and Domsch, 1988). Anderson and Domsch (1990) found that the ratio was lower in a crop rotation than in a monoculture. They also found that the ratio decreased with time (they sampled plots with up to 80 years of crop rotation), and concluded that a lower respiratory ratio indicates a more mature and stable system. In the current study, no treatment differences were seen for qCO_2 other than on the first sample date. The respiratory ratio showed that the microbial biomass was functioning at a similar capacity in the two systems. The respiratory ratio seems most valuable as an indicator of long-term system change, and the duration of the current study (three years) was insufficient to reveal significant changes in microbial function. Alternatively, the two experimental treatments did not differ enough to change this parameter significantly. Similar conclusions can be drawn for the ratio of biomass C to organic C.

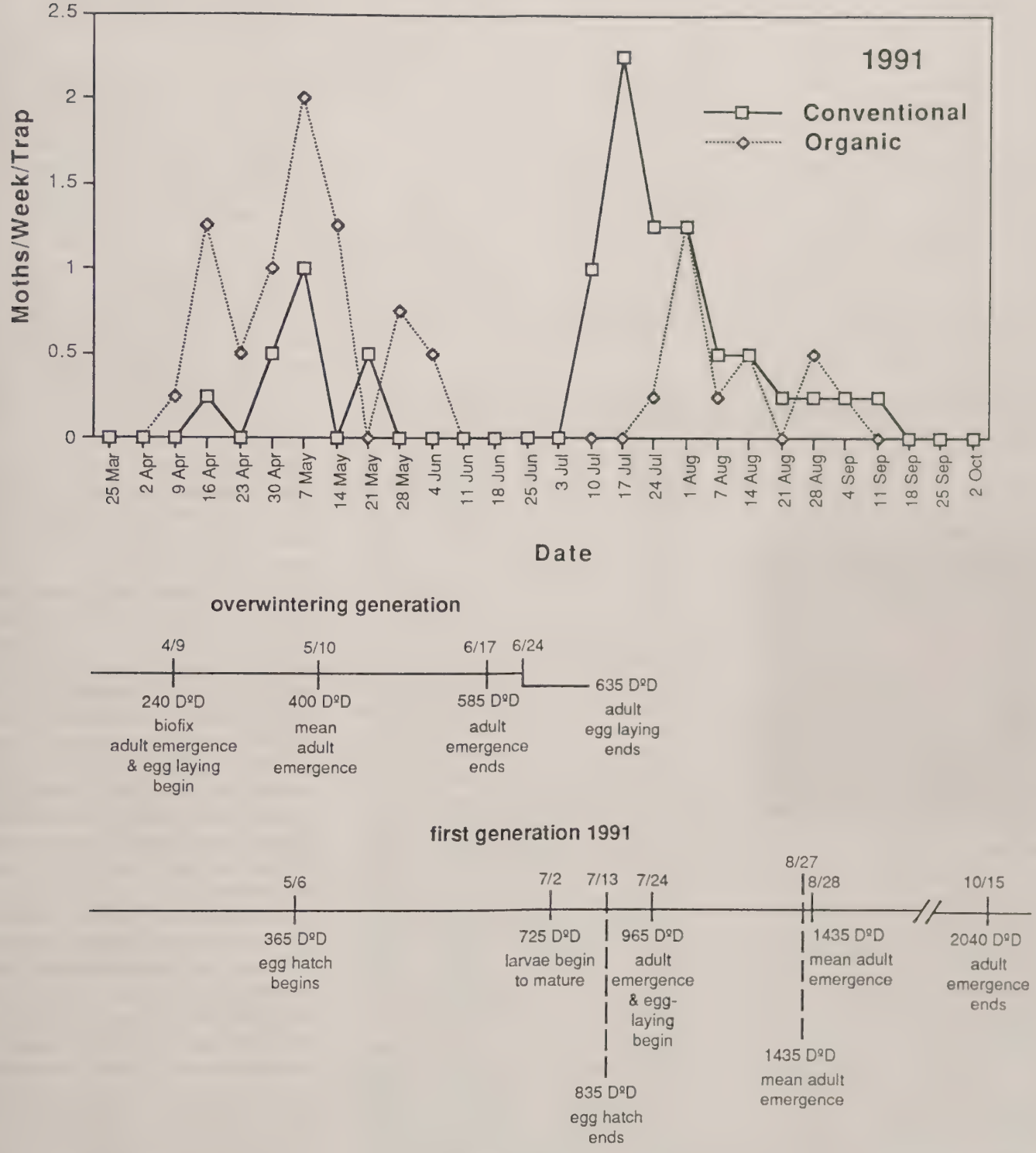

Figure. 12. Mean weekly codling moth male capture in sticky wing traps and IMPACT degree-day model. Rider conversion study, Watsonville, CA, 1991.

Table 7. Weed biomass (g/m^2, dry weight), 1990-1992.

Date	Treatment	Dry weight
September 1990	Conventional	160b[1]
	Organic	306a
April 1991	Conventional	10b
	Organic	105a
	Mulch	0.4c
October 1991	Conventional	107a
	Organic	196a
	Mulch	0.2b
April 1992	Conventional	5c
	Organic	180a
	Mulch	59b

[1] Means within a column for a given date differ significantly ($p<.05$) if followed by a different letter (Duncan's Multiple Range Test).

Table 8. Comparative yield and growth factors at third-year harvest of mulched and unmulched rows in an organic, semidwarf Granny Smith production system, 1991.

	Mulched	Unmulched
Yield (kg per tree)	26.3	25.3
Apples per tree	163	174
Trunk circumference (cm)	20.8	21.4
Mean terminal length (cm)	41.7	36.9

PMN was significantly greater in the OPS on two of the three dates it was measured. PMN is considered a sensitive measure of the active soil organic N pool, the fraction that is accessible to soil organisms and enzymes. Our results support the hypothesis that changes in PMN can be detected before changes in total N or organic C (Duxbury and Nkambule, 1994).

Key pest abundance

Low pressure from codling moth and well-timed management programs in both the OPS (CMGV and mating disruption dispensers) and the CPS (insecticides) resulted in less damage in both systems. These less plots were smaller and narrower than ideal for evaluating pheromone-based mating disruption, and we accepted this limitation to our conclusions about effectiveness. However, the absence of a second in-season generation of codling moth (coinciding with harvest of most apple varieties in the coastal production region) is characteristic of the cool, sea-level coastal valley climate in most years and offers a distinct bioenvironmental advantage to these sites. Borden (1931) observed that foggy coastal evenings and rapid drops in ambient temperature below flight thresholds could limit flights of codling moth in the Watsonville area of coastal California.

Increased leaf damage by tentiform leafminer and decreased parasitism by a complex of hymenopterous parasitoids may be caused by insecticides in the CPS (Maier, 1982; Ridgeway and Mahr, 1985). A complex of parasitoids known to attack tentiform leafminer in coastal California is disrupted by insecticides (Varela and Welter, 1992). We observed this effect in the CPS in contrast to the OPS. We postulate a similar mechanism for increased fruit scarring by orange tortrix and apple pandemis in 1991. The parasite or predator complex that regulates secondary lepidopterous pests in organic production systems should be identified and its contribution to mortality evaluated. However, leaf damage by increased white apple leafhopper in the OPS does not fit with the speculation for other secondary pests. The potential impacts of leafhoppers on leaf physiology and fruit production should be evaluated in organic systems, and the natural control factors and behavioral factors involved in leafhopper abundance should be determined.

Weed species and biomass

Although weed growth was significantly greater in the unmulched organic plots than in the mulched organic plots, no decline in fruit yield was observed in the unmulched plots. This finding indicates that in the first three years of conversion, vigorous semidwarf apple trees 7 to 9 years of age do not encounter yield-reducing competition from the weedy cover in the OPS. However, this cover could lead to increased rodent damage. Timely winter and spring in-row weeding in a small area around the base of trees is required to limit rodent damage. The polypropylene mulch effectively eliminated the need for this hand-weeding from 1989-1991. However, as a layer of organic matter built up on the mulch surface (applied compost top dressing, cut weed biomass, and leaf litter), rescue grass became established, with penetrative roots first observed in spring 1992. It is important to remove these weeds before the roots penetrate the fabric. This weeding is easy before the root zone is established below the surface of the fabric mulch. Although mulching could be more effective than mowing and tillage and is as efficient as herbicide use, its initial expense ($619/ha for materials) and the trees' lack of competition from weeds may counter its advantages.

The semidwarf MM.106 rootstock has been shown to bring coastal plantings of Delicious and Golden Delicious apples into bearing earlier than a domestic seedling rootstock (Micke et al., 1992). Typically, this system is brought into production in the second or third year following planting. In coastal central California, an organic production system planted on a single row pattern would allow easier nonchemical weed control by mowing and tillage. Mowed biomass from tree aisle vegetation, blown into the row, could also be used to control weeds if a reduced tree density is considered as an alternative to double rows. Longer-term monitoring will be required to demonstrate the economic

Table 9. Comparative apple production systems costs and yields, 1989-1991.

	Conventional ($/ha)				Organic ($/ha)		
	1989	1990	1991		1989[1]	1990[2]	1991
Labor[3] (hr)	(631.50)	5207.58	5467.95	5741.33	(691.05)	5701.18	6271.30	6898.43
Field Power[4] (hr)	(26.25)	599.50	629.48	660.95	(30.25)	693.75	728.48	764.90
Total Materials Cost		1669.28	1752.75	1840.40		1954.33	2052.05	2153.35
Interest		408.00	448.80	471.25		525.58	551.85	579.45
Certification Fees (CCOF)						25.00	25.00	103.00
Total Costs		7884.36	8298.98	8713.93		8899.84	9628.68	10499.13
Yield (metric tons/ha)		41.3	33.4	35.6		54.6	36.3	45.2
Value ($/ha)[5]		9251.20	7481.60	8971.20		12230.40	1118.40	15187.20
Return ($/ha)		1336.64	-817.38	257.27		3330.56	1551.72	4688.07

[1] Transitional year, no premiums.
[2] First fully certified year.
[3] Labor at $8.25/hr (1989).
[4] All field power is 50 hp tractor.
[5] Based on the following apple prices per metric ton: conventional—$224 in 1989 and 1990, $252 in 1991; organic—$308 in 1989 and 1990, $336 in 1991.

benefits and useful life of weed barrier mulch for controlling weeds in a double-row organic production system.

Production costs and income

The transitional (1989) and certified organic (1990, 1991) production systems consistently showed higher profits, because of the increased tonnage and the premium prices obtained by this unsorted fruit. Klonsky et al. (1994) estimated the individual costs of organic apple management operations and arrived at a similar overall figure for cost of production. However, profits and premiums were not as great as the profit estimates published by Cook et al. (1989) for "high input" certified organic Granny Smith apples in Santa Cruz County in 1989. They estimated the value of 22 (short) tons of certified organic apples at $16,174, a selling price above $735/(short) ton. This is much greater than the prices in this study, and may stem from erroneously applying the highest wholesale price for boxed apples to unsorted field tonnage. However, our field estimates of production costs are similar to those of that study, in that the OPS required more labor (cultural costs) than the CPS because of hand thinning and hand weeding. Higher materials costs in both studies accurately reflect the increased number of microbial insecticide and pheromone applications and higher tractor time. Klonsky et al. (1994) have also given detailed labor and materials budgets for this organic production system.

A farmgate price premium of 33 to 38% for organic apples accounts for a higher return per hectare in the OPS. However, the general price levels for apples from both systems reflect weak demand and oversupply.

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USDA, EPA PLAN WOULD CLEAN UP ANIMAL FEEDING OPERATIONS

The USDA and EPA have announced a draft voluntary and regulatory strategy to reduce the pollution from animal feeding operations. The draft strategy's goal is for all animal feeding operations to develop and implement comprehensive nutrient management plans by the year 2008. These plans would include manure handling and storage, application of manure to the land, record-keeping, feed management, integration with other conservation measures, and other manure utilization options. Of the country's 450,000 animal feeding operations, about 6,600 are large operations with more than 1,000 animals, called concentrated animal feeding operations. The regulatory part of the plan intends to focus its permitting and enforcement activities on these large operations. An estimated 15,000 to 20,000 livestock operations will be required to develop comprehensive nutrient management plans as part of permits under the Clean Water Act; the other operations will be encouraged to implement voluntary plans. EPA and the states will expand their efforts to ensure that all permits include comprehensive management requirements, including land application conditions, and will revise regulations by December, 2001. In addition, EPA will revise national environmental guidelines to limit discharge from poultry and swine facilities by December, 2001, and national guidelines for cattle and dairy facilities by 2002.

The draft strategy contains "significant flaws," according to Martha Noble of the Sustainable Agriculture Coalition, including:

- There is no moratorium on construction of large-scale animal feeding operations while USDA and EPA revise their standards and regulations.
- The strategy places the entire financial burden of dealing with animal feeding operations on taxpayers and individual growers.
- The strategy ignores sustainable, non-confined livestock production systems as an alternative to concentrated, confined animal feeding operations.

The draft strategy is available on the Internet at http://www.nhq.nrcs.usda.gov/cleanwater/afo or http://www.epa.gov/owm/afostrat.htm

SUSTAINABLE AG MAY HAVE ROLE IN REDUCING GREENHOUSE GASES

Policymakers are now focusing on the potential of farms and new farming techniques to help fight global warming by offsetting emissions from burning fossil fuels, according to an article late last year in *The Washington Post.* The goal is to get farms to act as carbon "sinks" which would soak up carbon dioxide from the atmosphere and store it for decades or even centuries. "A few simple practices, applied across the U.S. Corn Belt, could transform farms into carbon-dioxide sponges that sop up millions of metric tons a year of the chief greenhouse gas blamed for global warming," the article said. "In a 15-year experiment at the Rodale Institute, [Laurie] Drinkwater and two colleagues discovered they could dramatically increase the carbon content of soils simply by changing crop rotations and cutting back on chemical fertilizers." Drinkwater said that a switch in farming practices in the Corn Belt could reduce the country's net carbon dioxide emissions by up to two percent, at the same time the farms themselves would also burn less fuel and purchase fewer chemicals.

FARM CHILDREN FACE SIGNIFICANT HEALTH RISKS, SAYS REPORT

Children who live on or near agricultural land, or whose families work in the fields, are "likely to be the most pesticide-exposed subgroup in the United States," and face "particularly significant health risks," according to a new report from the Natural Resources Defense Council. These children come in contact with pesticides through "residues from the parents' clothing, dust tracked into the house, contaminated soil in outdoor play areas, food brought directly from the fields to the table, and contaminated well water," the report concluded. NRDC recommends that pesticide tolerances be set low enough to protect farm children from cumulative health risks, and that the EPA phase out Category I acute toxic pesticides, most hazardous neurotoxic organophosphate and carbamate pesticides, endocrine disrupters, and carcinogens, while developing and promoting alternative pest management practices. "Trouble on the Farm: Growing Up with Pesticides in Agricultural Communities" is $10.50 plus $3 from NRDC Publications Department, 40 West 20th St., New York, N.Y. 10011.

Response of corn, soybean and wheat crops to fertilizer and herbicides in Ohio compared with low-input production practices

D.A. Munn, G. Coffing, and G. Sautter

Abstract. *Synthetic inputs have become the norm in cash grain production in the Midwest U.S., but do they really increase profitability compared with low-input production methods? This study reports a comparison of cash grain yields, quality and profitability under two management systems, low-input practices and conventional practices. The crop sequence was corn, soybean, and wheat - medium red clover green manure. Low-input practices included crop rotation, manure, and mechanical weed control. Conventional practices added starter fertilizer, side-dress N for corn, early spring top-dress N for wheat and herbicides to the low-input practices. The conventional inputs increased yields in each of the five growing seasons, 1992-96. Weather, N fertilizer and weed control appeared to explain much of the yield and grain quality variation. Soil P and K levels were maintained or increased by manure use. Plant foliar analysis indicated that soil macronutrients were mostly in the sufficient range for both management systems. Economic return in excess of the additional cost of the fertilizer and herbicides averaged \$172.63 ha^{-1} for soybean, \$165.63 ha^{-1}* for corn and minus \$19.19 ha^{-1} *for wheat over the five-year study. Fertilizer and herbicides did pay with corn and soybean, but not with wheat under the conditions of this study.*

Key words: low-input grain crop, conventional grain crop system, economic return to synthetic inputs

Introduction

During the 1980s and early 1990s, some farmers and agricultural scientists in the United States began to question the wisdom and the sustainability of decoupling plant and animal agriculture, which stimulated the movement toward crop production systems that were narrowly-focused on one or two cash grains and dependent on fossil fuel derived synthetic inputs such as fertilizers and pesticides (Francis, 1990; Harwood, 1993; Strange and Miller, 1994). A reexamination of conventional crop production systems and comparison with older "organic" or newer low-input practices were called for by Vorst, (1990). Many of these calls for new studies focused on maintenance of soil fertility, use of animal manure and other organic by-products such as biosolids, green manure, cover crops, tillage practices and pest management strategies, and using contemporary plant varieties and hybrids and modern planting rates and dates, (Vorst, 1990; Francis, 1990).

Many researchers have reported a reduction in crop yield and an increase in pest control problems during the transition period from conventional to organic or low-input systems of crop production (Chase and Duffy, 1991; Liebhardt et al.1989; Temple et al. 1994). These reductions are often temporary and usually recover to higher levels after several years of organic or low-input practices. However, they seldom return to the levels achieved with conventional fertilizer and pesticide inputs. Hanson et al. (1997) recently published a comparison of farming systems in the mid-Atlantic states from 1981 to 1995. They concluded that in the most recent two five-year periods, organic production methods achieved corn (*Zea mays* L.) and soybean (*Glycine max* [L]) yields comparable to conventional methods, but required more family labor and management. In their study, the cost of family labor could greatly affect the profitability of organic production methods and there seemed to be diseconomies of scale, that is per-unit costs increased as the farm size increased. They also reported a favorable transition from wheat (*Triticum aestivum* L.) interseeded with red clover (*Trifolium pratense* L.) to hairy vetch (*Vicia villosa*) seeded in the early fall after wheat harvest

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as able to supply more nitrogen to succeeding crops.

This study reports five years of data from northeastern Ohio with the most important cash grains: corn, soybean and soft red winter wheat. Grain yield and quality in systems with low-input production practices are compared with the same practices plus synthetic fertilizer and herbicide inputs (called the conventional inputs). Replicated plots of 0.25-.28 ha were managed with commercial sized (six-row) equipment. The goals of this study were to answer the following questions: (1) Do fertilizer and herbicide inputs increase yield or quality of these grain crops when applied in a background of low-input practices? and (2) Does the monetary value of the increased production offset the cost of additional production inputs?

Materials and Methods

The research site was located on the Ohio State University Agricultural Technical Institute Apple Creek Farm near Apple Creek, Ohio. Soil types at the research site included Fitchville silt loam with a 2 to 6% slope (fine-silty, mixed, mesic, Aeric Ochraqualf), Glenford silt loam with a 6 to 12% slope in the eroded phase(fine- silty, mixed, mesic, Aquic Hapludalf), and Orrville silt loam with a 0 to 2% slope (fine-loamy, non-acid, mesic, Aeric Fluvaquent) (Bureau et al. 1984).

The total area was approximately 4.85 ha (18 plots @ 0.27 ha each). The rectangular area was split into three fields (A, B, and C) and each field was split in half lengthwise. Three replicates of each crop were oriented along the length of each field. Soil differences were minimized by blocking the replicates and assigning one replicate to each map unit. The two treatments were low-input practices and conventional practices (low-input practices plus synthetic fertilizer and herbicides as appropriate). Treatments were assigned by a coin flip for each replication in each strip and remained the same throughout the experiment.

During each year, paired "t" tests were used to compare grain yields, grain quality and other treatment-related effects. Agronomic practices for each crop during each of the five years of this study are given in Tables 1, 2, and 3. The crop sequence was corn, soybean, and wheat interseeded with medium red clover as a green manure. The clover was allowed to grow in the wheat stubble and then both stubble and the clover were incorporated by chisel-plowing and secondary tillage (one or two passes with a till-all) in preparing the land for corn.

Table 1. Agronomic practices used for wheat.

Year	1992	1993	1994	1995	1996
Low input practices common to both treatments					
Cultivar	'Cardinal'	'Dynasty'	'Freedom'	Oat 'Armor'	'Dynasty'
Seed rate (kg ha^{-1})	119	134	122	—	112
Planted (date)	9-28-91	10-23-93	10-15-93	—	10-13-95
Tillage	Chiseled/ Secondary Tillage	No Till	No Till	—	No Till
Red Clover					
Seed Rate(kg ha^{-1})	10	11.2	9	—	9
Date Clover Seeded	3-92	3-93	4-94	—	3-96
Harvested	8-7-92	7-21-93	7-18-94	—	7-25-96
Liquid Hog Manure (l ha^{-1})	—	41760 (80-108-79)[1]	—	—	—
Additional inputs for conventional practices					
Starter Fertilizer (kg ha^{-1})	224 6-26-26	—	241 6-26-26	—	252 6-26-26
Topdress N (kg ha^{-1})	36 (urea)	90 (urea)	68 (urea)	—	52 (urea)
Herbicides active ingredient (kg ha^{-1})	0.56 2,4D Amine	None	0.67 2,4DB	—	0.84 2,4DB
Date applied	5-4	None	5-10	—	5-6
Extra Inputs					
Costs ($ ha^{-1})	70.69	26.23	148.52	—	103.10

[1] Numbers in parenthesis are the available N-P_2O_5-K_2O from manure analysis

In 1991, the year before the actual experiment commenced, the A plots were planted to oat (*Avena sativa* L.) followed by fall-seeded wheat, the B plots to soybean and the C plots to corn. The A plots began with wheat in 1992, the B plots with corn and the C plots soybean. All plots went through the rotation for five years. The A plots of soybean were harvested so late in the fall of 1994 that fall seeding of wheat was deemed inadvisable. The A plots had oat interseeded with red clover in 1995, and corn continued in sequence in 1996.

The low-input treatment (system) received no synthetic fertilizer or herbicides, but in all other respects were the same as the conventional treatment. Both treatments received rotary hoeing and mechanical cultivation to control weeds in 1992, 1993, 1994 for corn and soybean production. In 1995 and 1996 only the low-input plots were rotary-hoed or cultivated. This was done to achieve a more valid comparison of mechanical versus chemical weed control. The appropriate costs were calculated for each treatment. Both treatments

Table 2. Agronomic practices used for corn.

Year	1992	1993	1994	1995	1996
Low input practices common to both treatments					
Hybrid	Schlessman SX655	Schlessman SX655	Pioneer 3525	Pioneer 3525	Bird B630
Seeds ha^{-1}	70,640	73,100	78,790	74,100	76,800
Planted (date)	5-15	5-13	5-4	5-3	5-31
Chiseled (date)	4-29	4-29	4-21		4-11
Secondary Tillage	5-15	5-12	5-4	5-3	5-23
Cultivations[2]	2		2	1	1
Hog Manure Liquid ($l\ ha^{-1}$)[1]	73,000	41,800	59,800	—	83,500
($N\text{-}P_2O_5\text{-}K_2O$ equiv, $kg\ ha^{-1}$)	(157-213-156)	(90-121-88)	(129-175-128)	—	(179-242-177)
Harvested	11-17	11-12	11-08	11-01	11-20
Additional inputs for conventional practices					
Starter Fertilizer ($kg\ ha^{-1}$)	128 6-26-26	224 (6-24-24)	179 (6-26-26)	224 (6-26-26)	179 (6-26-26)
Extra N ($kg\ ha^{-1}$)	168 (28-0-0)	None	151 (28-0-0)	175 (28-0-0)	168 (28-0-0)
Herbicides active ingredient ($kg\ ha^{-1}$)	Atrazine 0.29 Cyanazine 0.91 Metolachlor 2.8	Atrazine 0.29 Cyanazine 0.91 Alachlor 2.73	Atrazine 0.29 Cyanazine 0.91 Alachlor 2.73	Acetochlor 0.78 & Atrazine 0.54 on 5-6 Dicamba 0.28 Crop Oil Conc. 2.2 on 6-21	Dicamba 0.28 & Atrazine 2.22
Date applied	5-15	5-14	5-13	5-6 and 6-21	6-2
Extra Inputs					
Costs ($\$\ ha^{-1}$)	157.33	99.57	160.67	228.05	178.88

[1] Numbers in parenthesis are available $N\text{-}P_2O_5\text{-}K_2O$ from manure analysis
[2] Cultivated only the low input plots

received the same kind and rates of manure and were planted and harvested on the same days, except for some conventional soybean plots that had to be replanted because of herbicide injury in 1993 and 1994. The costs of production include these replanting costs. Plant seeding rates and varieties were the same in the paired comparisons each year.

All work was done with commercial farm equipment: 75-105 Kw (100-140 horsepower) tractors, six-row planter, cultivator and combine. Grain yields were measured by weighing the entire harvest from each plot in the field with a weigh wagon. Wheat straw was harvested as big round bales for on-farm use. The yields of straw were not significantly related to the treatments and the straw yields are not reported here.

Leaf tissue was collected from each crop as follows: soybean (20 upper trifoliolate leaves at early flowering) in 1992, corn (20 ear leaves at initial silking) in 1993 and 1996, and wheat (30 upper leaves at early flower stage) in 1994, for foliar analysis by the Ohio State University Research Extension Analytical Laboratory (REAL), Wooster, Ohio. Soil samples (15 cores per plot obtained from a depth of 0-20 cm) were collected in the spring of 1993-96 and were analyzed by the REAL according to standard methods (Dhanke, 1980). Grain quality measurements such as moisture, oil content, protein and test weight were performed by the Ohio State University Department of Agronomy Grain Quality Laboratory. Protein, oil and moisture were measured with a Tecator 1225 Near Infrared Whole Grain Analyzer (Perstorp Analytical, Silver Spring, MD 20904). Some grain moisture measurements were made with a drying oven and balance.

Weed notes were made by a single individual (Munn) walking the plots at several times during each crop growing season and assigning a degree of weed infestation score (range 1 to 10) and noting the most abundant weeds in their relative order of abundance.

Economic analysis

Grain yields were adjusted to a standard moisture content and a drying cost appropriate for the moisture content was calculated. Northeast Ohio cash grain prices at harvest each year were used to calculate the value of the crop. This means that the same yield increase for corn, for example, could have a different value as the market price and drying cost per bushel fluctuate. While this may confound the performance of the systems, production costs will vary over time and market prices are subject to change from season to season.

The production costs and market value of the crop have a great impact each year on profitability. The analysis is really only a partial budget for the enterprises since all the costs were the same except for the costs of purchasing and applying fertilizers and herbicides. The analysis reports the increase/decrease in grain production times the increase/decrease in production costs and the gross returns minus the extra costs of purchasing and applying fertilizers and herbicides based on custom or

standard rates in our area. The five-year average returns are integration not only of cropping system performance, but also costs of production and market value of the crop. This is the variable faced by farmers.

Results and Discussion

Yield and grain quality

The conventional treatment which included fertilizers and herbicides, frequently but not always out-yielded the low-input treatment for corn, soybean and wheat (Table 4). Also in Table 4 note the Wayne County average yields for each crop as compiled by the Ohio Crop Reporting Service. With the soybean crop these differences were significant ($P<0.05$) each year except 1995, whereas with corn the differences were significant only in 1994-96 and the wheat only in 1992. Overall yields (Table 4) were related to the amount and distribution of rainfall over the growing season (Table 5).

The impact of climate on corn, soybean and wheat crops in Ohio is described in the *Ohio Agronomy Guide* (Agronomy Extension Staff, 1995). The lowest corn grain yields occurred in 1993 and 1996, the seasons with the lowest and highest total precipitation and the driest months of July and August, when corn is tasseling and grain filling occurs. The 1996 growing season was very wet, especially early in the summer (Table 5). August rainfall also supports pod filling for soybean under Ohio conditions. Wheat yields varied the least with the growing season moisture supply (Tables 4 and 5), but wheat in Ohio needs the most water in May and early June, just after heading.

Weed infestation (Table 6) leads to the conclusion that much of the yield increase by the conventional treatment can be attributed to the superior weed control achieved with herbicides. The influence of weed competition and rainfall are in agreement with King and Buchanan (1993). Weeds were a tremendous problem. The proper timing of a cultivation and the precision used, will determine the effectiveness of mechanical weed control. Whether a farmer can achieve effective weed control will be an important factor in the difficult transition that low-input/ organic farmers face as they go from chemical to mechanical weed control.

Table 3. Agronomic practices used for soybean.

Year	1992	1993	1994	1995[2]	1996[2]
Low input practices common to both treatments					
Cultivar	'Resnick'	'Resnick'	'Edison'	'Edison'	'Edison'
Seeds ha^{-1}	434,700	469,300	501,410	654,500	691,600
Planted (date)	5-22	5-25	5-8	6-9	5-31
Chiseled (date)	4-29	4-29	4-21	4-6	4-11
Secondary Tillage (date)	5-15	5-20 & 5-25	5-18	5-23 & 6-6	5-29
Rotary Hoe (date)	6-2	6-1	6-7	6-20	6-9
Cultivations (date)	6-30	6-15 & 6-25	6-16 & 6-22	6-26 & 7-5	6-16
Liquid Hog Manure[1] (l ha^{-1})	73,000	41,800	—	—	83,500
(N-P_2O_5-K_2O equiv, kg ha^{-1})	(157-213-156)	(90-121-88)			(179-242-177)
Harvest	10-23	10-15	10-17	10-13	11-1
Lime (Mg ha^{-1})		4.5			
Additional inputs for conventional practices					
Starter Fertilizer (kg ha^{-1})	190 (0-0-60) Broadcast	—	151 (6-26-26)	134 (0-11-47) Broadcast/ Plowdown	—
Herbicides active ingredient (kg ha^{-1})	Linuron 1.12 Metolachlor 2.80	Linuron 0.56 Chlorimuron ethyl 0.03 Metolachlor 2.80 Severe herbicide injury Replanted 2 of 3 plots 6-18	Flumetsulam/ Metolachlor 2.42	Dimethenamide 1.21 Linuron 0.56 Chlorimuron ethyl 0.030	Thifensulfuron 0.018 Quizalofop 0.42
Date applied	5-22	6-2	5-24	6-14	6-3
Extra Inputs					
Costs ($ ha^{-1})	135.97	86.45	90.92	107.30	49.72

[1] Numbers in parenthesis are the available N-P_2O_5-K_2O from manure analysis
[2] rotary hoe and cultivation used only in low input plots

Grain quality, as measured by protein, oil (if appropriate), and test weights, were different among the three crops (Table 7). For corn, the conventional treatment had higher protein in 1992 and 1994. This is, perhaps, a response to the sidedress N fertilizer received by the conventionally-treated corn. The oil content and test weight (kg l^{-1}) were not significantly different between treatments during the first three years of the study (Table 7).

With soybean, the protein was higher

Table 4. Grain yields by treatment and year.

Crop and Treatment	Grain Yield (t ha^{-1})[1]				
	1992	*1993*	*1994*	*1995*	*1996*
Corn Wayne Co. Avg.	10.16	4.93	8.78	7.52	7.28
Corn Conventional	9.40	7.59	10.91	8.79	7.09
Corn Low Input	8.84	4.96	5.22	5.02	1.82
Probability (t)[2]	0.107	0.066	0.031	0.004	0.004
Soybean Wayne Co. Avg.	2.73	1.88	3.12	2.62	2.43
Soybean Conventional	3.02	1.87	3.29	2.05	2.47
Soybean Low Input	1.99	0.58	0.91	1.45	1.43
Probability (t)	0.038	0.014	0.001	0.230	0.028
Wheat Wayne Co. Avg.	4.22	2.78	3.66	Oats	2.50
Wheat Conventional	3.72	3.60	4.99	—	2.49
Wheat Low Input	2.22	3.23	4.60	—	2.04
Probability (t)	0.030	0.15	0.27	—	0.200

[1] Yields were adjusted to 15.5% moisture for corn and 13% moisture for soybean and wheat. Wayne County average yields from Ohio Department of Agriculture Annual Report & Statistics.
[2] Based on t test comparing conventional and low input treatments

Table 5. Rainfall for growing seasons 1992-1996.

Month	Monthly Precipitation (cm) by Year					28 Yr. Avg.[1]
	1992	1993	1994	1995	1996	
April	5.7	9.1	10.8	2.4	14.9	8.2
May	5.1	4.1	5.0	14.5	14.9	8.4
June	5.5	14.1	13.1	12.7	12.5	8.4
July	21.1	5.1	9.4	7.5	9.1	10.6
August	10.2	1.0	11.9	15.2	7.8	8.6
September	8.7	8.5	3.5	3.2	17.9	7.8
October	4.5	7.6	1.6	12.7	6.9	5.3
Season Total	60.8	49.6	55.4	75.8	84.0	58.3

[1](Bureau et al., 1984 p.138)

for the low-input treatments in two of the three years (Table 7). The conventional soybeans received a complete starter fertilizer only in 1994 when the protein content did not differ between the treatments. The oil content was higher for the conventional treatment in 1993. The soybean test weights were similar for the treatments.

The conventionally-treated wheat had a higher protein content than the low-input wheat in 1993 and 1994. The difference is likely due to spring topdressing of N fertilizer for the conventional treatment. Microbial mineralization of manure N may have occurred too late in the spring to increase the number of stalks and, thus, the number of grain heads. The wheat test weights were mixed, with the conventional tests being higher in 1992 and 1993 and the low-input tests higher in 1994.

Plant foliar and soil nutrient analyses

Because of budget limitations, foliage from only one crop was sampled and analyzed each growing season (Table 8). Both the conventional and low-input treatments resulted in nutrient levels that were consistently in the sufficient range for the three crops (Agronomy Extension Staff, 1995). Low-input wheat and corn foliage were lower in N than the conventional treatment which had received extra N fertilizer. This is consistent with the grain protein results. Low-input soybeans had higher leaf N ($P<0.05$) and higher seed protein as noted in the discussion of grain quality. The conventional treatment for soybean fertilization in 1992 was a simple broadcast application of muriate of potash (0-0-60); a complete starter with N was used only in 1994. For soybean, both treatments were similar and within the sufficient range for K content.

Soil P and K (Table 9) tests were adequate for corn, soybean and wheat in Ohio where Tri-state extension soil fertility recommendations call for a K level of 100 mg kg^{-1} for soils with a CEC of 10 cmol kg^{-1} , and Bray P1 available P of 15 mg kg^{-1} for corn and soybean and 25 mg kg^{-1} for wheat (Vitosh et al. 1995). Manure was able to increase soil P levels much more readily than soil K levels at the rates applied (Table 9).

Weed control

For the first three years, all corn and soybean plots received weed control in the form of chisel-plowing, secondary tillage, rotary-hoeing and one or two cultivations. The mechanical weed control was moderately successful during this phase of the study. There was often a failure to completely control weeds in the crop rows. Temple et al.(1994) noted that weed control and N fertility maintenance were the main obstacles to overcome in the transition from conventional to low-input/ organic practices in California's Sacramento Valley. During the last two years reported here only the low-input treatments received rotary-hoeing or cultivation to control weeds. The conventional treatment received two or more herbicides and starter fertilizer in the row (corn only) that promoted early growth. The conventional weed control was quite good (Table 6) except for three problem species: dogbane (*Apocynum cannabinum* L.), Canada thistle (*Cirsium arvense* L.) and hedge bindweed (*Convolvulus sepium* L.).

Table 6. Weed control scores means and sample standard deviations (where 1 = no weeds and 10= total weed cover).

DATE	FIELD	CROP	WEED SCORES CONVENTIONAL	WEED SCORES LOW INPUT	PROB (t)
			1993		
Oct. 8	B	Soybean	2.5	7.0	0.005
Oct. 29	A	Corn	2.7	3.3	0.115
			1994		
	C	Corn	1.0	8.2	0.003
June 8	A	Soybean	3.7	6.7	0.085
	B	Wheat	2.7	3.0	0.150
	C	Corn	1.2	6.3	0.004
July 7	A	Soybean	2.0	7.0	0.003
	B	Wheat	1.7	3.0	0.102
			1995		
	A	Oat	8.0	6.7	0.248
June 2	B	Corn	5.7	9.3	0.009
	C	Soybean	2.0	3.3	0.058
July 25	A	Oat	4.3	3.7	0.261
	C	Soybean	2.0	6.7	0.020
Oct. 3	C	Soybean	2.3	5.7	0.044
Nov. 21	B	Corn	2.0	6.0	0.005
			1996		
June 17	A	Corn	4.3	9.7	0.003
	B	Soybean	2.8	8.0	0.008
July 15	A	Corn	1.7	5.7	0.001
	B	Soybean	3.7	4.3	0.393
	C	Wheat	3.3	4.0	0.248
Aug. 6	A	Corn	2.3	7.7	0.004
	B	Soybean	3.3	7.3	0.004
Aug. 27	B	Soybean	4.7	9.7	0.001
Oct. 30	A	Corn	4.0	7.7	0.013
	B	Soybean	4.3	8.7	0.006

Treatment differences in weed control were smallest for the wheat crop where the densely planted crop effectively competed with the weeds. Even here, the low-input treatment had more Canada thistle and common ragweed (*Ambrosia artemisiifolia* L.). We used 2,4-DB (Butyrac) herbicide in the conventional wheat because of the red clover green manure crop. In the low-input soybeans, common and giant ragweed (*Ambrosia trifida* L.) survived in crop rows and then created serious competition for soybeans by late summer. In 1994, wet weather interfered with timely cultivation and weed growth increased resulting in very low soybean yields in the low-input treatment. Herbicide injury was observed in 1993 and 1994. The 1993 treatment, Lorox Plus (linuron and chlorimuron ethyl) at 0.98 kg ha^{-1} and metolachlor at 2.8 kg ha^{-1} showed injury symptoms after rotary-hoeing. The same tank mix in another field that was not rotary-hoed did not show this injury. It may also have been triazine carry over from the previous year's corn herbicide. Herbicide injury was observed in soybean again in 1994.

Economic analysis

Partial budgets were prepared to determine whether the cost of additional inputs, i.e., purchased fertilizer and herbicides, was accounted for in the value of the extra crop produced. Table 10 gives the economic comparisons for the five years with the three crops. Because weather factors caused major differences in crop grain yield and weed control effectiveness, the most meaningful assessment of the study focuses on average returns of revenue and profit or loss. The economic analysis showed wheat to exhibit very different responses, ranging from a large profit returned to fertilizer and herbicide in 1992 to a slight profit in 1993, to a substantial loss associated with the purchase of extra inputs in 1994 through 1996. When averaged over four years of this study (oat economic returns from 1995 were not included) there was a net loss with wheat of \$19.19 ha^{-1}. With corn the yearly returns to the extra inputs ranged from \$113.55 ha^{-1} in 1992 to \$308.70 ha^{-1} in 1996. When averaged over the five years, the net return to extra inputs was \$165.63 ha^{-1}. With soybean the net returns to extra inputs ranged from a low of \$23.42 ha^{-1} in 1995 to a high of \$345.80 ha^{-1} in 1994. The five-year average return to purchased inputs was \$172.63 ha^{-1}. Controlling weeds in the soybean crop was a difficult problem. Consequently, the most expensive purchased input for the soybean crop was the herbicides that effectively controlled weeds and enhanced yields.

Conclusions

This study has attempted to address the question, "Does fertilizer and herbicide

Table 7. Grain quality indicators.[1]

Crop and Treatment	Year	Protein	Oil	Test Wt.
		---------- % ----------		kg/l
Corn Conventional	1992	10.3	—	0.70
Corn Low-Input	1992	9.9	—	0.68
Probability (t)		0.026	—	0.230
Corn Conventional	1993	9.7	4.8	0.74
Corn Low-Input	1993	8.8	4.6	0.74
Probability (t)		0.500	0.500	0.400
Corn Conventional	1994	9.0	4.4	0.72
Corn Low-Input	1994	8.2	4.5	0.70
Probability (t)		0.027	0.26	0.118
Soybeans Conventional	1992	42.4	20.0	0.71
Soybeans Low-Input	1992	43.3	19.6	0.71
Probability (t)		0.011	0.104	0.48
Soybeans Conventional	1993	40.4	21.2	0.75
Soybeans Low-Input	1993	43.7	19.9	0.77
Probability (t)		0.020	0.050	0.270
Soybeans Conventional	1994	41.8	19.4	0.74
Soybeans Low-Input	1994	42.3	19.9	0.70
Probability (t)		0.116	0.172	NA[2]
Wheat Conventional	1992	—	—	0.64
Wheat Low-Input	1992	—	—	0.60
Probability (t)		—	—	0.024
Wheat Conventional	1993	13.0	—	0.77
Wheat Low-Input	1993	12.1	—	0.60
Probability (t)		0.020	—	0.010
Wheat Conventional	1994	13.7	—	0.71
Wheat Low-Input	1994	12.1	—	0.74
Probability (t)		0.005	—	0.043

[1] Protein and oil determined by near infrared spectroscopy.
[2] Samples molded before testing.

use make economic sense when used in conjunction with low-input crop production systems''? Crop rotation (corn, soybean, wheat-green manure), animal manure and mechanical weed control were used. In comparing systems, no market premium was assumed for low-input produced grain. Based on this experiment, nitrogen fertilizer for corn and herbicides for corn and soybeans normally do pay their way under these circumstances. To compete effectively without herbicides and fertilizer under these conditions, one would need to explore certification as an organic grower in order to sell grain for a premium in a niche market. Also, weed control by mechanical means must be implemented with proper timing and precision to be effective. Crop diseases and insect pests were not observed to be a problem under the conditions of this study, perhaps because of the three-year crop rotation and use of adapted cultivars. Soil P and K levels were maintained by use of animal manure.

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Table 8. Plant foliar analyses results.

Treatment	N	P	K	Ca	Mg
			%		
			Corn Foliar Analysis		
Low-Input 1993	2.46	0.32	2.25	0.54	0.26
Low-Input 1996	2.57	0.30	1.86	0.47	0.25
Conv. 1993	2.68	0.32	2.50	0.55	0.25
Conv. 1996	2.79	0.29	1.86	0.50	0.25
Probability (t) 1993	0.036	0.44	0.100	0.410	0.37
Probability (t) 1996	0.078	0.186	0.500	0.280	0.500
OSU Sufficiency Range	2.90-3.50	0.30-0.50	1.91-2.50	0.21-1.00	0.16-0.60
			Soybean Foliar Analysis August 1992		
Low-Input	5.80	0.415	1.79	0.78	0.23
Conv.	5.57	0.410	1.73	0.86	0.24
Probability (t)	0.030	0.431	0.335	0.160	0.380
OSU Sufficiency Range	4.25-5.50	0.30-0.50	2.01-2.50	1.36-2.00	0.26-1.00
			Wheat Foliar Analysis May 12, 1994		
Low-Input	3.63	0.45	2.97	.257	.117
Conv.	4.47	0.42	3.08	.313	.130
Probability (t)	0.004	0.101	0.09	0.034	0.058
OSU Sufficiency Range	3.25-4.5	0.25-0.50	2.0-3.0	.25-1.00	.15-.60

Table 9. Soil test[1] summaries 1993-96.

Treatment - Date	pH	P (mg/kg)	K (mg/kg)	CEC (cmol/kg)	Organic Matter (%)
Low-input 4/1/93	6.2	70	104	9.6	2.34
Conventional 4/1/93	6.2	82	125	9.6	2.39
Probability (t)	0.47	0.304	0.05	0.50	0.395
Low-input 3/30/94	6.3	93	148	9.1	—
Conventional 3/30/94	6.2	96	158	9.6	—
Probability (t)	0.13	0.40	0.27	0.19	—
Low-input 3/30/95	6.5	86	150	9	—
Conventional 3/30/95	6.4	94	168	9	—
Probability (t)	0.16	0.39	0.24	0.71	—
Low-input 11/20/96	6.4	85	119	10.4	3.0
Conventional 11/20/96	6.2	94	136	10.7	3.0
Probability (t)	0.066	0.125	0.021	0.064	0.419

[1] Soils were sampled 0 to 20 cm depth and analyzed by Ohio State University Research Extension Analytical Laboratory.

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Biotechnology May Threaten Sustainable Farming, Says N.Y. Times

Though biotechnology is being heralded by industry as the tool to "rescue the American food chain," that "version of sustainable agriculture may threaten precisely those farmers who pioneered sustainable farming," according to a cover story late last year in *The New York Times Magazine.* "Organic farmers are up in arms: the widespread use of Bt in biotech crops is likely to lead to insect resistance, thus robbing organic growers of one of their most critical tools."

By planting genetically altered plants, "we have introduced something novel into the environment and the food chain, the consequences of which are not—and at this point, cannot be—completely understood." One unknown is the resistance problem, which industry scientists say can be postponed for 30 years, but other scientists say will come within three to five years. In addition, the USDA has long been "hostile" to organic methods, author Michael Pollan writes.

Table 10. Economic analysis of returns to fertilizer and herbicide inputs.

	1992	1993	1994	1995[1]	1996
			Wheat		
Incremental Yield Response kg/ha	1503	370	398	315	445
Value ($/kg)[2]	0.1151	0.1016	0.1063	0.1000	0.1214
Extra Value ($ ha^{-1})	172.94	37.62	42.26	31.52	53.97
Extra Costs Inputs ($ ha^{-1})	70.69	26.23	148.52	102.60	138.10
Profit/Loss ($ ha^{-1})	102.26	11.41	(106.26)	(70.89)	(84.13)
Profit/Loss Avg. 5 Yr. ($ ha^{-1})			($19.19)		
			Corn		
Incremental Yield Response kg/ha	565	2634	5928	3783	5283
Value ($/kg)[2]	0.774	.0978	.0786	.1191	.0923
Extra Value ($ ha^{-1})	43.79	257.70	414.96	450.55	487.58
Extra Costs Inputs ($ ha^{-1})	157.34	99.57	160.55	228.06	178.83
Profit/Loss ($ ha^{-1})	(113.55)	158.12	254.41	220.50	308.70
Profit/Loss Avg. 5 Yr. ($ ha^{-1})			$165.63		
			Soybean		
Incremental Yield Response kg/ha	1037	1293	2383	566	1044
Value ($/kg)[2]	.1966	.2358	.1834	.2310	.2464
Extra Value ($ ha^{-1})	203.87	304.95	437.19	130.71	257.28
Extra Costs Inputs ($ ha^{-1})	135.97	86.45	91.39	107.29	49.72
Profit/Loss ($ ha^{-1})	67.90	218.50	345.80	23.42	207.55
Profit/Loss Avg. 5 Yr. ($ ha^{-1})			$172.63		

[1] Oat crop. Oat profit/loss not included in wheat 4 year average.

[2] 1992 and 1993 Prices Received by Farmers Ohio Crop Reporting Service. 1994-96 Local Cash Markets at Harvest.

Voters Support Restrictions on Factory Farms

Voters in Colorado and South Dakota supported restricting large commercial hog facilities on ballot initiatives Election Day last year. In Colorado, voters approved by 64 percent an initiative regulating the construction and operation of large commercial hog feeding facilities, and the disposal of manure and wastewater to minimize odor and water pollution.

In South Dakota, 60 percent of voters approved a constitutional amendment to prevent concentrated animal feeding operations from acquiring or otherwise obtaining an interest in any land used for farming in the state, essentially saying that only family-controlled farms can operate in the state.

According to The Des Moines Register, "Al Tank, a top official of the National Pork Producers Council, said environmental restrictions approved by Colorado voters and a ban on corporate ownership of hog facilities by South Dakota citizens are 'ominous precedents.'' A New York Times editorial said that "the votes against hog farms should encourage the Environmental Protection Agency to push ahead with tougher clean water regulations for big agricultural operations."

Consumers Union Calls for EPA to Ban Two Classes of Insecticides

A recent Consumers Union report calls for the EPA to phase out two classes of insecticides: high risk organophosphates and carbamates used on children's foods. It also recommends a doubling of funding for research on pesticide alternatives. The report, "Worst First: High-Risk Insecticides, Children's Foods, and Safer Alternatives," reviews the 40 uses on nine fruit and vegetable crops that together account for a large portion of children's dietary insecticide exposure and risk.

"Our 'Worst 40' uses should be high-priority targets for EPA action under the Food Quality Protection Act's 'worst first' mandate," the report says. If the EPA eliminated the "Worst 40" insecticide-food combinations identified, the report estimates that the risks associated with the nine crops would decrease by about 95 percent.

The report also concludes that "there are many viable alternatives growers can use to manage crop pests." The alternatives listed include bio-based alternatives and natural control products, such as pheromone products used in mating disruption; and bio-IPM practices, such as crop rotation, soil fertility and irrigation management, building and maintaining populations of natural enemies of insects, and measures to block or disrupt reproduction.

The report's other recommendations include: the EPA should reduce or eliminate residues from all organophosphate and carbamate uses on key children's foods; USDA and Congress should fund farmer education on safer alternatives to the "Worst 40" uses; EPA should expedite registration for safer alternatives; and USDA and Congress should double funding for research on IPM and safer alternatives.

BOOK REVIEWS

Mycology in Sustainable Development: Expanding Concepts, Vanishing Borders. Edited by Mary E. Palm and Ignacio H. Chapela. 1997. Parkway Publishers, Box 3678, Boone, NC 28607. viii + 306 pp. ISBN 1-887905-01-04. $40, paper.

This book is the outgrowth of a workshop held at the 1995 annual meeting of the Mycological Society of America. The editors define sustainable development as "—the maintenance of economic, social and industrial growth while preserving the integrity of the biosphere," later expressing surprise at the role that fungi play in it. The book is divided into four sections detailing how fungi are used, could be used, or inventoried in sustainable enterprises. The sections are: Non-timber forest products; Inventory and monitoring; Environmentally friendly technologies; Diversification-novel products. Each contribution has a bibliography, taking up fifty-one total pages, and a composite bibliography is also included, taking forty pages. In all 29% of the book is taken up by references! Four contributions deal with mushrooms as non-timber forest products. Three of these deal with the pine mushroom, or American matsutake (*Tricholoma magnivelare*) in North America. A comprehensive treatment by Scott A. Redhead is especially informative and, to my mind, the most valuable contribution in the book. Among other contributions that seemed especially well-done and timely were a highly technical assessment of similarity indices, by R. E. Tulloss; an analysis of bioprospecting, by I. H. Chapela; and a wide-ranging discussion of fungal biocontrol of weeds in the sustainability setting, by R. W. Barreto and H. C. Evans. Two papers on mycorrhizae and three papers on inventory and monitoring of mushrooms and other fungi were fairly general, but could be useful to those relatively uninitiated in these subjects.

Everything considered, the book is probably worth its $40 price for the references alone. For the person interested in wild mushrooms as a sustainable crop, it is a storehouse of information and might prove indispensable. Other potential buyers should examine a bookstore or library copy to see how it might fit individual needs.

Jack D. Rogers, Professor and Chairman, Department of Plant Pathology, Washington State University, Pullman, WA 99164-6430.

Pigs, Profits, and Rural Communities. Edited by Kendall M. Thu and E. Paul Durrenberger. 1998. SUNY Series in Anthropological Studies of Contemporary Issues. State University of New York Press, State University Plaza, Albany, NY 12246. 208 pp. ISBN 0-7914-3888-0. $17.95, paper.

This edited volume by anthropologists Kendall M. Thu and E. Paul Durrenberger presents the case against the industrialization of the hog industry. The editors and 16 contributing authors generally oppose the ongoing reorganization of the U.S. hog industry away from largely independent operations, which vary in size and character, toward a more homogenous structure dominated by very large operations that are either under contract to integrating firms, or owned outright by such firms. Thu and Durrenberger state in their introduction (p. 4) that "the contributions presented here provide a legitimate counterweight to overly rosy rural development scenarios often painted for rural communities considering industrialized swine facilities."

The volume contains evidence of increased costs in human health and declines in rural community well-being and environmental quality, stemming from industrial swine production. In addition, the authors consistently attack the precepts accepted by proponents of industrial swine production, including many business leaders and academics: that industrialization of the hog industry is driven by consumer preferences for leaner pork, and by the increased efficiency and lower per unit cost of industrial operations. They offer alternative explanations for the dramatic rise of industrial hog production. These include preferential pricing for large-scale contract operations over independents; the interests of food manufacturers, not final consumers, in particular carcass characteristics; tax policy biased toward capital-intensive, investor-owned (rather than operator-owned) production; and the ability of agribusiness investors to influence government economic and environmental policy to favor industrialized production.

Overall, the book is an informative, accessible, and useful piece of scholarship. Its strength lies in the diversity of its contributors, who include social and biological scientists, farmers, rural activists, and a former legislator. The book is divided into four parts, along with an introduction and conclusion. The introduction is an articulate 'voicing' of the authors' perspectives, setting the stage for the 11 individual chapters that follow. Part I is concerned with the effects of industrialized hog production on rural communities. It consists of two anthropological community case studies, as well as a narrative from family hog producers who relate how structural change has affected their lives and their community. Part II details the health hazards for workers in industrialized hog operations, the psychological effects of living near industrialized hog operations, and the impacts on water quality from such operations. Part III deals with the political economy of the North Carolina and Iowa hog industries and examines the poultry industry as a potential, unfavorable, future model for the hog industry. Part IV critiques the industrial model further, offering possible alternatives designed to be more environmentally sound and economically and socially equitable.

The conclusion is authored by Walter Goldschmidt, who made the original finding that rural communities surrounded by large numbers of small- to moderate-sized,

independently operated farms fared better than communities surrounded by fewer, larger, corporate-linked operations. In this section, Goldschmidt offers a wide-ranging critique of industrial agriculture, arguing forcefully that socially constructed rules and institutions arising from political and economic agendas, rather than impersonal market forces and technology development, drive industrialization.

The book is well-written and presented in an understandable manner. For these reasons it could be used in undergraduate courses in sociology, economics, anthropology, political science and public policy. In addition, the book is a timely contribution. Anyone who wishes to understand the motivations of groups and individuals working to pass legislation hobbling the expansion of industrialized hog production should read this book.

Rick Welsh, Policy Analyst, Henry A. Wallace Institute for Alternative Agriculture, Greenbelt, MD 20770.

INSTITUTE NEWS

New Reports Examine Soil Quality, Industrialization

Two new reports recently published by the Wallace Institute examine soil quality's contribution to environmental health, and industrialization in U.S. rural communities. *From the Ground Up: Exploring Soil Quality's Contribution to Environmental Health,* by Edward Jaenicke of the University of Tennessee, investigates the current state of scientific knowledge on soil quality and points out research gaps that must be filled before soil policy can target potential social benefits.

The report describes several timely soil-quality issues, including the potential for healthy soils to sequester vast amounts of atmospheric carbon, which contributes to global warming; the need to incorporate an understanding of healthy soil quality when increasing the efficiency of farm inputs and profits through precision farming; and the benefits of a healthy soil ecology for food safety.

Agricultural Industrialization in the American Countryside, by Emery Castle of Oregon State University, offers an approach for rural communities as they face conflicts resulting from the spread of industrialization, particularly large confined animal feeding facilities. These conflicts include farmer against farmer, rural neighbor against farmer, rural townspeople against immigrant farm laborers, environmental advocates against agri-business, and local versus state governments. The report explains the concept of "rural capital stock," in which natural, human, and social capital elements are used to measure and evaluate the effects of industrialized farms.

Both reports are available on the Wallace Institute's Web site at http://www.hawiaa.org; each is $10 from the Wallace Institute, 9200 Edmonston Road, #117, Greenbelt, MD 20770; (301) 441-8777.

Wallace Board Meets in Iowa, Names President's Council

The Wallace Institute's Board of Directors held its mid-year meeting in Ames, Iowa, last September, when members attended the Dick and Sharon Thompson Annual Field Day and Farm Tour in Boone, Iowa. They also toured a Murphy Family Farms hog facility, and the Optimum Quality Grains operation in Des Moines, which is a joint venture of Pioneer Hi-Bred International, Inc., and the DuPont Co.; that evening, the board attended a reception sponsored by the College of Agriculture at Iowa State University and the North Central Regional Center for Rural Development. Most of the board meeting was devoted to reviewing a proposed long-range plan to guide the Institute for the next 5 to 10 years. Following the meeting, the board attended a dinner at the Wallace House in Des Moines.

Institute President Dr. Cornelia Flora has announced the members of the 1998-1999 President's Council, formed eight years ago to provide guidance and support for Wallace Institute activities in promoting a more sustainable agricultural system in the United States and abroad. Members are: Dr. Charles Benbrook, Benbrook Consulting Services; Norman A. Berg, Washington Representative, Soil and Water Conservation Society; Robert Gray, Resource Management Consultants; Ralph Grossi, President, American Farmland Trust; Dr. R. Jim Hildreth, Elmhurst, IL; Ms. Dana Jackson, Land Stewardship Project; Dr. Dennis R. Keeney, Director, Leopold Center; Hon. Patrick J. Leahy, U.S. Senate; Dr. Ned S. Raun, Stillwater, OK; Ronald L. Rosmann, farmer, Harlan, IA; R. Neil Sampson, President, The Sampson Group, Inc.; Edward Sills, Pleasant Grove Farms, Pleasant Grove, CA; Dr. David G. Topel, Dean, College of Agriculture and Director of Experiment Station, Iowa State University; and Dr. Stephen Viederman, President, Jessie Smith Noyes Foundation.

Annual Thompson Farm Report Details Research

"Alternatives in Agriculture," the 1998 annual report published by Thompson On-Farm Research, details the research conducted by Dick and Sharon Thompson on their farm in Boone, Iowa. The new report updates all previous reports, and includes major changes in fertility, economics, and livestock research. The publication of the report and the 1998 research work is made possible by the financial support of Mrs. Jean Wallace Douglas through the Wallace Institute. The report is available for $10 from Thompson On-Farm Research, 2035 190th St., Boone, IA 50036-7423; (515) 432-1560.

UPCOMING EVENTS

February 16, Minnesota Organic Farming Conference will be held in St. Cloud, MN; contact Prescott Bergh, Energy and Sustainable Agriculture Program, Minnesota Department of Agriculture, (651) 215-0367; e-mail prescott.bergh@state.mn.us

February 17, Swine System Options Conference will be held at Iowa State University, Ames, IA; contact Rich Pirog, Leopold Center for Sustainable Agriculture, (515) 294-3711; e-mail leocenter@iastate.edu

February 18, "Passing on the Farm" workshops will be held in York, PA; contact Pennsylvania Farm Link, Point Shopping Center, #205, Harrisburg, PA 17111; (717) 558-7726; e-mail pafarmlink@redrose.net

February 18-20, New Orleans; March 18-20, San Francisco; April 8-10, Indianapolis; and May 6-8, Andover, MA; "Communities Working for Wetlands" will be held; contact Terrene Institute, 4 Herbert St., Alexandria, VA 22305; (703) 548-5473; e-mail terrinst@aol.com

February 18-21, Bio Fach 99, the World Organic Trade Fair, will be held in Nuremberg, Germany; contact Kathy Donnelly, Concord Expo Group, (978) 371-2203.

February 20, "Creating Successful Grower Marketing Cooperatives" will be held in Albany, N.Y.; contact Liz Callan, Regional Farm and Food Project, (518) 426-9331; e-mail lizbrian@juno.com

February 22, 30th Annual North American International Erosion Control Association Conference and Trade Exposition will be held in Nashville, TN; contact IECA, 1-800-455-4322; ecinfo@ieca.org

February 22-23, USDA's Agricultural Outlook Forum 1999 will be held in Arlington, VA; contact USDA, (202) 314-3462; on the Internet, http://www.usda.gov/oce/waob/agforum.htm; e-mail agforum@oce.usda.gov

February 22-26, "Feeding and Balancing the Soil," a short course, will be held in Mt. Palomar, CA; contact the Center for Living in Harmony, (760) 749-9634; e-mail info@livinginharmony.org

February 23-25, Advanced Organic-Biodynamic Vegetable Production Workshop will be held in St. Croix, MN; contact Gail Kahovic, Michael Fields Agricultural Institute, (414) 642-3303.

February 26-27, "A Life Cycle Approach to Sustainable Agriculture Indicators," sponsored by National Pollution Prevention Center and the EPA, will be held in Ann Arbor, Michigan; contact Guntra Aistars, (734) 764-1412; e-mail guntra@umich.edu

February 27, "Adding Value: Promoting Health, Generating Wealth," the annual meeting of the Nebraska Sustainable Agriculture Society, will be held in Aurora, NE; contact Cris Carusi, (402) 471-0817; e-mail crisc@navix.net

RESOURCES

"How to Establish Goals: A Group Project for Farmers and Their Families," for whole farm planning, is $3 from The Minnesota Project, 1885 University Ave. West, #315, St. Paul, MN 55104; (651) 645-6159; e-mail Water007@gold.tc.umn.edu

"LandWorks," a land use subscription service for professionals, includes online discussions, publications, and a private Website for $125 a year; contact American Farmland Trust, One Short St., Northampton, MA 01060; 1-800-370-4879; e-mail LandWorks@farmland.org

"Pesticide Exposure Handbook" is $2, "DO NOT SPRAY" sign is $4.75, from Californians for Alternatives to Toxics, P.O. Box 1195, Arcata, CA 95518; (707) 822-8497; e-mail catz@reninet.com

"Pesticide Decision Tool" is available free from John Vickery, Institute for Agriculture and Trade Policy, 2105 First Ave., S., Minneapolis, MN 55404-2505; (612) 870-3430; e-mail jvickery@iatp.org; on the Internet, http://www.iatp.org/enviroag/pesticidesummary.htm

USDA's Farmer Direct Marketing Web Page, providing resources and information about direct marketing, is at http://www.ams.usda.gov/directmarketing

"Alternative Farming Systems: Economic Aspects" and **"Vegetables and Fruits: A Guide to Heirloom Varieties and Community-Based Stewardship, Annotated Bibliography/Resources Organizations/Historical Supplement"** are available from Alternative Farming Systems Information Center, National Agricultural Library, 10301 Baltimore Blvd., Beltsville, MD 20705; (301) 504-6559; e-mail afsic@nal.usda.gov; on the Internet, http://www.nal.usda.gov/afsic

"Vegetable Farmers and Their Weed-Control Machines," a 75-minute video, is $12 plus $3.50 shipping from Natural Resource, Agriculture, and Engineering Service, 152 Riley-Robb Hall, Ithaca, N.Y. 14853-5701: (607) 255-7654.

Proceedings from a workshop on climate change and carbon sequestration are available from Emery Roe, Center for Sustainable Resource Development, University of California at Berkeley, (510) 642-1599; e-mail emrnpa@nature.berkeley.edu

"Wetlands and Agriculture: Private Interests and Public Benefits" is available from the USDA's Economic Research Service, 1-800-999-6779; on the Internet, http://econ.ag.gov; or contact Ralph Heimlich, USDA/ERS, (202) 694-5477; e-mail heimlich@econ.ag.gov

"Working Trees for Livestock" is available from Nancy Hammond, USDA, National Agroforestry Center, East Campus, University of Nebraska, Lincoln, NE 68583; (402) 437-5178 ext. 11; e-mail nhammond/rmrs lincoln@fs.fed.us

"Reaping Havoc: The True Cost of Using Methyl Bromide on Florida's Tomatoes" is available for $10 plus shipping from Friends of the Earth, 1025 Vermont Ave., NW, #300, Washington, D.C. 20005; (202) 783-7400 ext. 239.

Guide for Authors

The American Journal of Alternative Agriculture (AJAA) publishes original research on biological, physical, or social science aspects of alternative agriculture. We particularly welcome multidisciplinary studies, but papers from a specific discipline also are invited. However, since AJAA readership is much broader than for a single-discipline journal, highly specialized terminology should be explained or avoided. The significance of a statement, or the reasoning behind a conclusion, may have to be spelled out more than in a more specialized journal. See Vol. 5, No. 1, pp 2 & 3, for an explanation of the various categories of articles.

Units

Research papers should use the International (SI, or metric) system throughout. Occasional use of common unit equivalents in parentheses is permitted.

Title page

The title page should give the following information (all flush left): 1) title of the paper; 2) names of the authors; 3) affiliation and office address of authors, and 4) disclaimers and publication number, if any. See examples in this issue of AJAA.

Abstract

The abstract should be 200 to 400 words suitable for readers from a broad range of disciplines. It should avoid highly-specialized terminology that might be appropriate for a single-discipline journal. Take particular care that the significance of the work is made clear, even to readers from a different field.

Key Words

Provide subject matter key words suitable for use in scientific indexing.

Reference List

When citing material that has been covered in more than one format, such as the typescript of a conference presentation and a journal article, preference should be given to the version that is most readily available, and that is likely to remain so. Generally this means standard publication channels, such as books, journals, and regular government report series. Unpublished or informally-published material should be cited only when no alternative form exists.

References should be listed in alphabetical order by author's name, and by year for a particular author (with letters after the year if needed). If a sole author is also the lead author of papers with multiple authors, use the following order: single author (by year); two authors (alphabetically by second author's name); three or more authors (by year). Repeat the author's name for each reference. Give the names of all authors in the reference; never use "et al."

Use full names of journals, institutions, conferences, etc., except for extremely familiar abbreviations like "Dept." Remember that an abbreviation familiar to you may not be familiar to readers outside your field. If in doubt, write it out.

The reference list uses no quotation marks, italics, boldface, or underlining. Only the names of books and periodicals are in initial capitals. Names of papers, book chapters, pamphlets, and bulletins are not capitalized.

Citing References

Cite references in the text by last name and year, with chapter or page numbers if the reference is a book or lengthy report. For two authors, give both names. Do not use "et al." unless there are at least three authors.

Footnotes

AJAA does not use bibliographic or substantive footnotes. All bibliographic references should be at the end of the text. Instead of substantive footnotes, include the material in the main text or consider eliminating it.

Manuscript Preparation

The entire manuscript, including abstract and references, should be typed on one side of standard-size paper, double spaced, with margins of at least one inch all around. Starting with the title page, label all pages in the upper righthand corner with the lead author's last name and the page number. Do not use hyphens unless the hyphen is part of the word.

Tables should fit on one page, be numbered consecutively with Arabic numerals, and be on a separate sheet. Every figure and table should be mentioned at least once in the text.

A detailed guide to formatting is available from the editor (address below).

Submission of Manuscripts

Submit four high-quality copies to Dr. Robert I. Papendick, Editor, American Journal of Alternative Agriculture, Department of Crop & Soil Science, 253 Johnson Hall, Washington State University, Pullman, WA 99164-6420. The cover letter should state that the manuscript is an original contribution that has not been published elsewhere in substantially the same form, that it is not currently under consideration elsewhere, and that permission has been obtained for any copyrighted material used.

How you can help support the scientific and educational needs of a sustainable agricultural system

A growing number of Americans have become concerned about the long-term sustainability of our food production system. Farmers and agricultural scientists are among those raising questions about the growing dependence of modern farming on nonrenewable resources, the depletion of our resource base through soil erosion, and heavy reliance on chemical fertilizers and pesticides. Continued heavy reliance on farm chemicals is questioned because they have become an expensive production input. Their widespread use also raises questions about human and animal health, food quality and safety, environmental quality, and the continued demise of family farms and rural communities.

Alternative farming methods address these economic and environmental challenges. Alternative production systems point the way toward more profits, more individual choice, enhanced environmental quality, and long-term sustainability for our food system. More must be done to develop effective ways to make sure research, education, and information sources are readily available to farmers who want to adopt these techniques.

The Henry A. Wallace Institute for Alternative Agriculture needs your help in meeting this challenge. We are a nonprofit tax-exempt research and education organization established in 1983 to encourage and facilitate the adoption of low cost, resource conserving, and environmentally sound farming methods. We work directly with government agencies, colleges and universities, producer groups, and other institutions that provide research, education and information services to farmers.

The Wallace Institute also provides these services:

- *A resource to lawmakers and others who influence agricultural research, education, and information policy*
- *A voice for alternative agriculture in Washington*
- *A sponsor of research and education outreach programs*
- *A national clearinghouse for information on alternative agriculture*
- *A publisher of reliable scientific information on agricultural sustainability*

If you're interested in helping us, please contact the Henry A. Wallace Institute for Alternative Agriculture, 9200 Edmonston Road, Suite 117, Greenbelt, Maryland 20770-1551. Telephone: 301-441-8777; E-mail: hawiaa@access.digex.net; Web site: www.hawiaa.org

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FOR ALTERNATIVE AGRICULTURE